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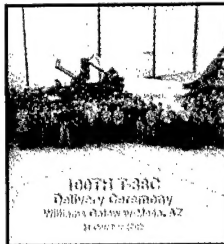
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*Lt Col Steve Brown, USAF, Lt Col Scott Miller, USAF,
and LTC Kent Schvaneveldt, USA*

The U.S. defense industry has more than a decade of experience implementing Lean process improvement methodologies to create value and eliminate waste in manufacturing and operations. While Lean implementation approaches differ, commercial companies and military commands consistently use highly skilled sensei, or *coaches* to help provide the discipline and structure needed to implement rapid and continuous change. This report documents key elements of coaching strategies from Lean implementations at 13 U.S. defense companies and military commands. The research indicates that differences in coaching strategies impact whether an organization will succeed in implementing Lean.

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APPLYING THEORY OF CONSTRAINTS PRINCIPLES AND LEAN THINKING AT THE MARINE CORPS MAINTENANCE CENTER

Mandyam Srinivasan, Darren Jones, and Alex Miller

The Maintenance Center for the Marine Corps Logistics Base, Albany, Georgia, launched a program in 2001 combining principles drawn from the Theory of Constraints and Lean thinking. The Center had been constantly plagued by apparent capacity shortages in virtually every

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department and additional manpower was being considered. An analysis using Theory of Constraints revealed that there was, in fact, more than adequate capacity to handle the workload. The perceived lack of capacity was due to policy constraints imposed on the Center as a result of a push scheduling mechanism. By implementing a pull system for scheduling repairs, the Center revealed capacity that had been masked. Today, the Center is ahead of, or on schedule, for 99 percent of the production lines where the Theory of Constraints *principles* have been implemented.

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LEAN NOW—USING A RESEARCH COMMUNITY TO UNDERSTAND CHANGE IN THE ACQUISITION ENTERPRISE

Eric Rebentisch, Ph.D. and Maj Ronald Jobo, USAF

Members of the Lean Aerospace Initiative (LAI) consortium have joined to pool experience and expertise to accelerate the adoption of Lean practices in military acquisition through an initiative called *Lean Now*. Lean Now has demonstrated that the concept of industry and government teaming for focused interventions can produce savings and accelerate change in the acquisition process. It also represents a systematic change method that lends itself to data collection and theory development. This paper outlines some of the findings to date, as well as implications for using such a model for research on the military acquisition system.

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A PERSON-CENTERED APPROACH TO SUSTAINING A LEAN ENVIRONMENT—JOB DESIGN FOR SELF-EFFICACY

David S. Veech

Toyota credits its team members for the success and sustenance of the Toyota Production System. The power of a highly skilled and motivated workforce is a significant competitive advantage for any company, in any industry. Toyota's team members collectively make hundreds of thousands of improvements to their work every year, reducing costs, reducing cycle times, and improving working conditions. Drawing on old and new research, this paper poses a theoretical explanation for why employees get involved and stay involved in transformational activities in organizations. It will explore relationships between corporate belief systems, job and employee satisfaction, and individual self-efficacy and then offer a way for companies to apply all of these theoretical ideas through two practical tools.

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Michael Joyce and Bettina Schechter

In 1999, Lockheed Martin developed an approach called LM21, for Lockheed Martin in the 21st century, to identify best practices for increasing efficiency and improving financial and operating performance. Leaders soon realized that best practice sharing was just one means to a higher end. The ultimate goal is to create a system that consistently achieves excellence for our customers, shareholders, and employees. We selected and implemented the management philosophies called Lean and Six Sigma. This article describes the Lean Enterprise at Lockheed Martin and the steps taken to make it a reality.

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T-38C TRANSITION TO LEAN

David D. Ott and James B. Davis

In 2000, the United States Air Force T-38 Avionics Upgrade System Program Office began to pursue Lean initiatives to reduce out-year program cost and delivery risk at the Boeing T-38C Upgrade facility located at Williams Gateway Airport facility in Mesa, Arizona. The T-38 Avionics Upgrade Program production system baseline plan was conventional for legacy aircraft upgrade and modification programs using a mass/craft assembly stationary dock approach. For a successful transition from conventional to Lean production, program management support is critical. The T-38 Program Office in St. Louis, Missouri proposed a four-phase approach to implementation. This approach and the benefits derived from the process are discussed.

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RAYTHEON—NEW CHALLENGES, NEW SOLUTIONS, AND DOCUMENTED RESULTS

Bob Blair and Jon McKenzie

Born from a multi-billion dollar debt and a driving commitment to customer success, Raytheon Six Sigma (R6σ™) has generated over \$2 billion in financial benefits resulting from over 3,000 projects. The culture change is now part of the fabric of Raytheon, with over 21,000 specialists, 1,200 experts, and 50 master experts guiding 76,000 employees to customer success. R6σ™ is now an integral part of the business strategy and is successful because it focuses on achieving success for customers while delivering results for the company. Guarding against complacency, Raytheon leadership ensures that R6σ™ continues

to evolve with the changing needs of the business. This paper highlights how R6 σ TM was used to forge a culture of customer focus and productivity improvement that led to higher levels of financial stability and customer success.

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TAMING THE AEROSPACE SUPPLY CHAIN— A CASE STUDY IN ORGANIZATIONAL INTEGRATION

DeWayne Searcy, Ph.D., Bradley Greene, Ph.D. and James Reeve, Ph.D.

Integrating suppliers and customers to capture supply chain efficiencies and effectiveness is critical in today's increasingly competitive environment. However, knowing this and doing it are two different matters. The methodology described here is an effective means to develop inter-organizational coordination. To achieve this coordination companies must first be made aware of the fundamental dynamics of supply chains. Awareness can disengage the individual personalities within different organizations and allow members of the supply chain to objectively view their value stream. Then, the individual organizations can define and measure the current state of their supply chain and finally agree to corrective actions that benefit the entire supply chain. Thus, our question is, how do firms that are traditionally isolated in their supply chain dealings introduce a greater degree of cooperation to their relationships? We will provide an answer to this question with a supply chain case study.

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A NOTE FROM THE EXECUTIVE DIRECTOR

As with most activities in life there comes a time when we need to make a change. The *Acquisition Review Quarterly* is at this juncture. While this journal has been successful in the past by providing useful research information to the Acquisition Community, it is time to improve its usefulness and to begin a new journey. To start this process we have renamed the journal the *Acquisition Review Journal*, and we have changed the way it looks. We have also restructured each future issue around a specific theme. Each new issue will focus on a specific topic area and will feature refereed articles from known experts as well as research articles from academia and the field related to that topic. The outcome will be a focused collection of articles highlighting different facets of a topic area, providing insight to the research streams currently underway, and providing some practical applications (wherever possible) of the research approach. This builds on the concept of taking research to practice, which is very important as we go to implement new ideas and new initiatives in our acquisition world.

Our first Special Edition highlights the topic area *Lean*. The U.S. defense industry has been implementing Lean process improvement methodologies for more than a decade to create value and eliminate waste in manufacturing activities and other operations. Since 1999, over a dozen Department of Defense (DoD) organizations have begun to systematically introduce Lean concepts to streamline operations and reduce costs. As we continue to learn from and share with our industry partners, we need to understand those things that are of most value and what we in government can leverage to improve our existing operations.

The basic principles of Lean originated at the Toyota Company in the 1950s. These principles—as outlined in the book *A Study of the Toyota Production System*, by Shigeo Shingo, in 1981—are: (1) the Minus-Cost Principle—to increase profit, cost must be reduced; (2) a Non-Stock Inventory—inventory should be acquired on a just-in-time basis; (3) Toward Flow Operations—promotes the concept of linking upstream processes; (4) Shortening Step Changeover Times—more efficient processes; (5) Elimination of Breakdowns and Defects—more effective processing; (6) Fusing Leveling and Non-Stock Production—level loading and mixed production; (7) Toward Comprehensive Integrated Flow Operations—breaking down traditional barriers; (8) Labor Cost Production—more efficient process; (9) From Mechanization to Automation—automate where it makes sense; (10) Maintaining and Developing Standard Operations—reducing variability; and (11) Toward a Kanban System—creating a self-regulating visual control system.

Building on these initial principles, we now see the incorporation of Six Sigma concepts and view the Lean approach as a method of improving both administrative and manufacturing processes. This current issue of the *ARJ* contains a collection of articles from invited authors and non-invited authors addressing this theme. We have consciously provided a variety of perspectives by selecting authors from different types of institutions to build a foundation for implementing Lean.

The first article, "Recommendations on Coaching Strategies for Implementing Lean," describes how Lean can be successfully implemented within a government environment through the use of internal or external coaches. This research, completed by the DAU Research Fellows, highlights the fact that using independent coaches can enhance the ability to successfully implement Lean processes in an organization.

The next three articles, submitted by our Academic Partners, address new thoughts on the implementation of Lean concepts. "Lean Now: Using a Research Community to Understand Change in the Acquisition Enterprise," (Massachusetts Institute of Technology [MIT]) discusses the initiatives and lessons learned in applying Lean to the F-22 program and addresses the feasibility of a government-industry focus on improving process interfaces to produce positive results. "Applying Theory of Constraints Principles and Lean Thinking at the Marine Corps Maintenance Center," (University of Tennessee) discusses the implementation of Lean processes at the Marine Corps Logistics Base located in Albany, Georgia and determined that policy constraints resulted in a misconceived lack of capacity to handle the workload. "A Person-Centered Approach to Sustaining a Lean Environment—Job Design for Self-Efficacy," (University of Kentucky) reminds us that all process improvement depends on people and offers a prescription for developing and maintaining workforce skills to implement and sustain improvements.

The next three articles are submitted by our Industry Partners and discuss how they have implemented Lean and measure their success. "Raytheon—New Challenges, New Solutions, and Documented Results," (Raytheon Corp) discusses Raytheon's Six Sigma™ program and its prescription for success. "The Lean Enterprise: A Management Philosophy at Lockheed Martin," (Lockheed Martin Corp) documents lessons learned from implementing Lean and why they consider it a holistic process applicable to all facets of the organization. "T-38C Transition to Lean," (Boeing Corp) describes the implementation of Lean in the T-38 program and the benefits derived from that process.

Our last article was submitted by a combination of academia and industry experts. "Taming the Aerospace Supply Chain: A Case Study in Organizational Integration" addresses the issue of inter-organizational coordination and the cooperation necessary to implement Lean in the supply chain process. Processes often involve a number of outside sources. This article considers the complexity of one process—the supply chain—and offers a method for Lean implementation.

In closing, I would like to thank everyone who has submitted articles and who has assisted with this publication. Please let us hear from you. Your thoughts and ideas are always welcome.

J. Robert Ainsley, Ed.D.
Deputy Executive Director, CDSC/Director Research

AUGUST—
NOVEMBER
2004



Fight test crewmember participates in a Lean Rapid Improvement Event at Warner Robins Air Logistics Center. He shares a Warfighter's perspective during creation of Value Stream Map for new aircraft maintenance flow.

RECOMMENDATIONS ON COACHING STRATEGIES FOR IMPLEMENTING LEAN

LT COL STEVE BROWN, USAF, LT COL SCOTT MILLER, USAF,
AND LTC KENT SCHVANEVELDT, USA

The U.S. defense industry has more than a decade of experience implementing Lean process improvement methodologies to create value and eliminate waste in manufacturing and operations. While Lean implementation approaches differ, commercial companies and military commands consistently use highly skilled sensei, or coaches to help provide the discipline and structure needed to implement rapid and continuous change. This report documents key elements of coaching strategies from Lean implementations at 13 U.S. defense companies and military commands. The research indicates that differences in coaching strategies impact whether an organization will succeed in implementing Lean.

The U.S. defense industry has more than a decade of experience implementing Lean process improvement methodologies to create value and eliminate waste. Since the late 1990s, over a dozen Department of Defense (DoD) organizations have introduced Lean to systematically streamline operations and reduce costs. While Lean implementation approaches differ, private companies and military commands consistently use highly skilled sensei, or coaches to help provide the discipline and structure needed to implement rapid and continuous process improvement. Ten specific recommendations concerning coaching strategies to effectively implement Lean in defense organizations are included here.

The five fundamental principles of Lean listed below are described in the book titled *Lean Thinking*, by James Womack and Daniel Jones (Womack & Jones, 1996).

1. Specify Value in the Terms of the Customer.
2. Identify the Value Stream.
3. Make the Process Flow.
4. Pull Value from the Customer.
5. Pursue Perfection.

These Lean principles originated in Japan with automobile production practices developed at Toyota in the 1950s. Decades later commercial manufacturing companies around the world began adopting these five principles. More recently, U.S. defense industry began introducing Lean in their production and maintenance facilities. While shop floor operations continue to be the initial focus of commercial Lean implementations, some companies have extended the application of these Lean principles to additional processes. The U.S. defense aerospace industry has numerous examples of applying Lean structured improvement methodology to system life-cycle processes including design, material management, repair, and overhaul.

While DoD primarily relies on contractors to design and produce defense systems, many DoD organizations are responsible for system life-cycle processes such as material management, repair, and overhaul. Management of defense system acquisition and sustainment processes is a core competency of the material commands within each of the military services and several defense agencies. Figure 1 highlights how Lean principles have migrated from Japanese automobile manufacturing to defense system life-cycle processes to integrated defense system management.

Among the first DoD aerospace system management organizations to experiment with implementing Lean on a large scale was Warner Robins Air Logistics Center (WR-ALC). Air Force Major General Haines, then Commander of WR-ALC, highlighted that the center saved millions of dollars on labor, material, and tools by applying

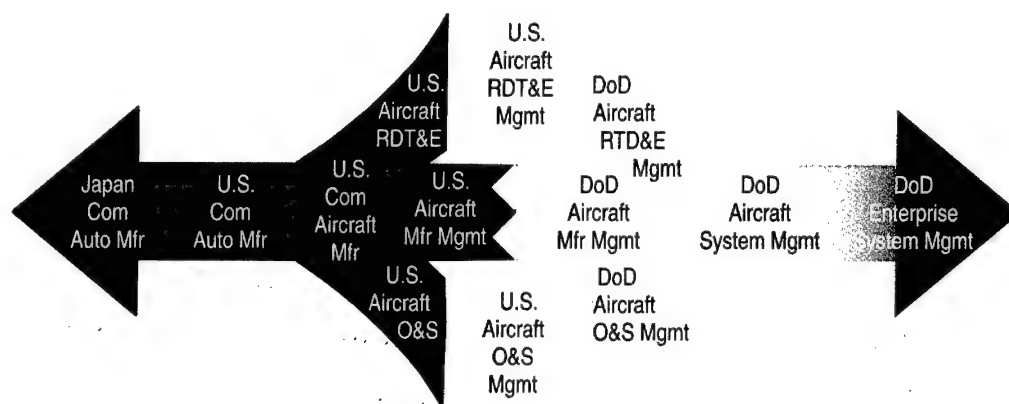


FIGURE 1. MIGRATION OF LEAN PRINCIPLES

Lean to depot-level repair of aircraft components. His successor, Major General Wetekam, expanded the centers Lean implementation to other weapon system sustainment processes. WR-ALC has significantly reduced the time to overhaul fighter and cargo aircraft. The other logistics centers within Air Force Materiel Command have also enhanced organizational performance by introducing Lean structured process improvement methodology (McCormack, 2002a).

Army Material Command (AMC) has also demonstrated improvements by introducing Lean to sustainment processes including maintenance and supply. In 2002, General Kern, Commander of AMC, expanded upon the Lean implementation at Red River Army Depot (RRAD). He launched a campaign to educate and train the AMC workforce about Lean principles and practices and provided funding for coaches at Army depots throughout the country (Hermes, 2002; McCormack, 2002a).

The U.S. Navy has applied Lean to the Intermediate Aircraft Maintenance Division at Naval Air Station Lemoore. The organization reduced the number of F-18 aircraft without engines from 26–28 per month to zero, and now a balance of engines is on hand to support the fleet (Jaynes, 2002).

"Defense systems management organizations are applying Lean structured, disciplined methodology for team-based process improvement to significantly boost performance."

In 2003, Air Force Materiel Command (AFMC) piloted the application of the Lean principles to joint DoD and defense processes. Three AFMC program offices within the Aeronautical Systems Center collaborated with their prime contractors to use Lean tools and practices to reduce time to accomplish flight-testing, contract modifications, and contract closeout. Defense systems management organizations are applying Lean structured, disciplined methodology for team-based process improvement to significantly boost performance.

Each of these early Lean implementations by military commands share common traits and continue to expand. All DoD organizations employed external coaches to help introduce Lean principles and practices. During the same period, other organizations, including a military command, have attempted to implement Lean using only internal coaches and failed. This poses a key question concerning coaches. Richard McCormack asked military leaders involved with implementing Lean the question, "Can an organization like yours initiate a Lean implementation on its own or do you need help doing it?" Their answers are published in his book titled *Lean Machines: Learning From the Leaders of The Next Industrial Revolution* (Hermes, 2002; McCormack, 2002a).

Major General Haines, Commander, WR-ALC: "You need help doing it and we have one of the best, we're using...Consultants. This was one of our learning experiences.... Our objective is to let them teach us for a year or so and by then we should have our own people who are ready to start running with it internally."

Lieutenant Colonel Frank Hart, Commander RRAD: "You need to read "Lean Thinking", then find yourself a firm like...that is on site on the ground and part of your team. If you think you can read the book and attend the seminar and do it yourself, you won't achieve it. You have to hire experienced mentors who have truly walked the walk—been in an organization that has implemented it."

During 2003, the Defense Acquisition University (DAU) Research Fellows investigated key elements of coaching strategy needed to successfully implement Lean in defense systems management organizations. While Lean principles and tools are fairly consistently defined, we found that coaching strategies for implementing Lean varied, and were not as well documented. Our study compared coaching strategies by organization size, mission, domain, and implementation phase. Through our research, we distilled that defense system management organizations should address the following six questions when building a coaching strategy for implementing Lean.

1. What is the scope of *responsibilities* for coaching staff to implement Lean?
2. What are the *credentials* needed to select coaches to implement Lean?
3. What is the *mix* of external and internal coaches needed to implement Lean?
4. What *tools* do coaches need to have knowledge/experience of to implement Lean?
5. What *performance measures* are needed to manage coaches implementing Lean?
6. What are the *incentives* coaches need to implement Lean?

Our research indicates that Lean—a structured, disciplined methodology for process improvement—can be applied to defense life-cycle system management activities. Although the Lean principles and tools are fairly formalized and straight forward, the strategies for implementing Lean vary. We analyzed and compared coaching strategies that companies and military services have employed to implement Lean in their organizations. The focus of the research was primarily on U.S. defense aerospace organizations. We found that different coaching strategies are needed during Introduction, Growth, and Sustainment phases of a Lean implementation.

DEFINITIONS AND SCOPE OF STUDY

Defense system management organizations were categorized by three dimensions: *size*, *domain*, and *mission*, which are independent variables in this study. The specific measures used to determine these domains are described below.

Size: *The number of people in an organization implementing Lean.* For the purpose of this research, a Small organization has less than 1,000 employees, Medium has between 1,000 and 5,000 employees, and Large has over 5,000 employees.

Domain: *The organization's primary business (DoD, Defense, or Other).*

Mission: *The primary emphasis of the organization with regard to the spectrum of defense system management activities.* For this research, the term *acquisition* refers to system development and demonstration work efforts plus production & deployment work efforts. Figure 2 depicts the life-cycle of systems management activities, as defined in DoD Instruction 5000.2, "Operation of the Defense Acquisition System."

People Interviewed: We interviewed over 50 people in organizations who were implementing or who had implemented Lean in organizations. Table 1 summarizes the organizations interviewed and their characteristics in terms of size, domain, and mission.

In addition to these formal interviews, we interviewed and observed other Lean practitioners from the following organizations or at the listed events.

- Lean Aerospace Initiative (LAI) is a non-profit consortium that provided coaches for introduction of Lean in three Aeronautical System Center (ASC) program offices. The LAI coaches were observed during program training of the Global Hawk program members in Rancho Bernardo, California in January 2003, and Value-Stream Mapping of the Global Hawk and F-22 aircraft programs in Dayton, Ohio in February 2003.
- Simpler Consulting Inc. is a private company that currently provides coaches to numerous DoD organizations including the Army, Navy, Air Force, and DoD headquarters staff. Simpler coaches were directly observed at Warner Robins Air Logistics Center and Corpus Christi Army Depot.

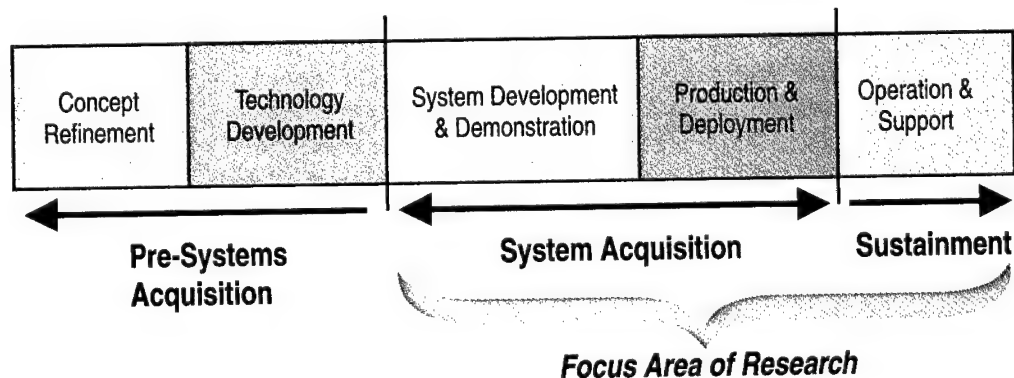


FIGURE 2. DEFENSE SYSTEMS MANAGEMENT ACTIVITIES

TABLE 1. ORGANIZATIONS INTERVIEWED

Organizations Interviewed	Parent Organization	Size	Domain	Mission
Corpus Christi Army Depot	Army Materiel Command	2,900	DoD	Sustainment
Aeronautical Systems Center	Air Force Materiel Command	9,300	DoD	Systems Acquisition
F-18 Engine AIMD	Strike Fighter Wing U.S. Pacific Fleet	700	DoD	Sustainment
Talley Defense Systems	Talley Defense Systems	200	Defense Industry	Acquisition & Sustainment
Metronics-Xomed	Medtonix	275	Other Industry	Acquisition & Sustainment
Northrop Grumman Air Combat Systems	Northrop Grumman	3,000	Defense Industry	Acquisition & Sustainment
Textron Systems	Textron Inc.	2,100	Defense Industry	Acquisition & Sustainment
Warner Robins Air Logistics Center	Air Force Materiel Command	13,000	DoD	Sustainment
Boeing Integrated Systems (Army Systems – LongbowApache)	The Boeing Company	4,000	Defense Industry	Acquisition & Sustainment
Lockheed Martin Aeronautics	Lockheed Martin Corporation	26,000	Defense Industry	Acquisition & Sustainment
Parker Aerospace	Parker-Hannifan Corporation	3,600	Defense Industry	Acquisition & Sustainment
Raytheon, Space & Airborne Systems	Raytheon	9,300	Defense Industry	Acquisition & Sustainment
Air Mobility Command	U.S. Air Force	147,000	DoD	Sustainment

- Lockheed Martin Commercial Systems Engineering is a private company that provides coaches and training for Lockheed Martin companies located in the eastern United States plus other American industries and government agencies. Lockheed Martin coaches were directly observed during training conducted at the companies training facility in Mount Laurel, New Jersey in June 2003.
- Raytheon Learning Institute is a training organization within Raytheon Corporation that provides Six Sigma Expert training within the organization. Raytheon coaches were directly observed during training conducted at Babson College, Massachusetts from July through September 2003.
- MainStream Management LLC, is a private company that provides coaches to guide Lean culture change activities currently supporting depot activities at Hill Air Force

Base, Utah. MainStream coaches were interviewed in June 2003 and directly observed at Hill Air Force Base in October 2003.

- Lean Shipbuilding and Repair Forum 2, Seattle, Washington, April 2003.
- LAI Annual Plenary Conference, Dayton, Ohio, March 2003.
- International Lean Manufacturing Conference, Lexington, Kentucky, May 2003.
- Lean Enterprise Institute (LEI) Value Stream Mapping training, Philadelphia, Pennsylvania, May 2003.
- Georgia International Lean Symposium, Warner Robins, Georgia, June 2003.

Lean Implementation Phase: Just as the defense system management spectrum is divided into several phases, Lean implementation can be divided into different phases based on workforce participation in Lean Events. While many leadership activities (like building and maintaining employee interest) are vital throughout an implementation, others require special attention during a specific phase. We used a 3-phase framework for implementing Lean to describe the application of the six coaching strategy elements. Figure 3 depicts these Lean Implementation Phases based on workforce participation in Lean events as we describe them in our research.

Research Hypothesis: If implementation of Lean is to be successfully introduced, grown, and sustained in defense system management organizations, then a robust coaching strategy is required.

Recommendations: The following are our top ten recommendations concerning coaching strategies to effectively implement Lean in defense organizations. These recommendations are based upon over 50 interviews with U.S. defense industry and DoD organizations that are implementing Lean. Findings are included from direct observation of 13 companies and military commands that are introducing, growing, or sustaining Lean. We believe these distilled experiences can help increase the probability that defense organizations can successfully implement Lean in system acquisition and sustainment processes.

Introduction:
Less than 10%

Growth:
10% - 80%

Sustainment:
Greater than 80%

FIGURE 3. LEAN IMPLEMENTATION PHASES

COACH RESPONSIBILITIES

Establish several levels of coaches with different degrees of responsibilities. Organizations should also define the responsibilities and time commitment expected for both internal and external coaches to support Lean Implementations. The following three levels of coach responsibilities were used by several defense contractors and are suggested for medium and large organizations.

- **Level I Coach:** Serve part-time. Facilitate discrete, narrowly focused, Lean process improvement events.
- **Level II Coach:** Serve full-time. Scope, plan, conduct, follow-up, and assess Lean process improvement events. Lead multiple events or more complex projects. Train and mentor Level I coaches. Develop specialized tools and techniques that target organization's priority needs.
- **Level III Coach:** Serve full-time. Scope, plan, conduct, follow-up, and assess multiple or integrated Lean process improvement events and events of greater complexity. Train and mentor Level I and Level II coaches. Provide training in specialized tools and techniques. Advise senior leadership on alignment of projects with organization's strategic objectives.

***"Require minimum Lean coaching credentials
when hiring external coaches."***

COACH CREDENTIALS

Require minimum Lean coaching credentials when hiring external coaches. All of the organizations studied that succeeded in maturing beyond the Introduction Phase used external coaches. Credential standards should include combination of relevant experience coaching Lean implementations in organizations within a similar environment (such as commercial, government, or non-profit) and mission area (such as such as manufacturing, maintenance/repair/overhaul, or supply-chain management). The credential standards should also specify minimum depth of Lean coaching experience (such as number of process improvement events or projects) and proof of results in improving performance of organizations (such as cost or time reduction).

A Defense organization, with over 8 years experience implementing Lean, has created evaluation criteria for qualification of external coaches. The rating system is available to dozens of subordinate companies, including many with defense system

acquisition and sustainment missions. Individual companies or business units within this corporation are expected to hire their external coaches from the approved list of consulting companies. Primary coaching credentials monitored are experience, results, and cost. Experience in specific environments, including manufacturing, material management, supply-chain management, and administrative domains highlighted. The Website describes experience and indicates relative cost for consultant services. Monetary savings are tracked for each external consultant or consultant's company, but not available on the Website.

"Primary coaching credentials monitored are experience, results, and cost."

A large DoD organization has established minimum qualifications for personnel hired as external coaches. The contract they issued states these minimum qualification standards.

The following six criteria are documented as required for *Sensei's providing services* in the Statement of Work used by this organization.

1. General Manager with profit and loss responsibilities leading a Lean conversion.
2. Demonstrated World Class results while leading the conversion.
3. Ability to communicate—lead and teach at all levels of organization.
4. In depth knowledge of Toyota Production System tools.
5. Change management skills.
6. Twenty (20) full cycles of Lean implementation, including value stream analysis, Kaizen, formal Lean training and alignment/assessments.

Select and Certify internal coaches to an organizational standard. This coach selection standard should include previous job performance, participation in Lean activities, and personal traits (such as confidence, communication skills and inclination toward innovation). The internal coach certification standard should include a combination of formal training, experience coaching Lean activities, and auditable results. Medium and large organizations should consider establishing formal certification standards for multiple levels of internal coaches. Suggested certification standards for three coach levels are described below.

- **Level I Coach:** 2–5 days of classroom training and experience facilitating at least one rapid process improvement event that achieves measurable results.
- **Level II Coach:** 2–6 weeks of additional formal training. 1–2 years experience planning and executing Lean process improvement events and completion of at least one complex project. Experience mentoring Level I coaches is also highly desirable. Review of credentials by board of Level III coaches may include an interview or exam.
- **Level III Coach:** Extensive experience planning and executing Lean implementations at multiple levels within multiple organizations. Experience should include breadth of Lean activities to introduction, growth, and sustainment phases, including coaching of highly complex projects. Additional specialized training and experience mentoring Level II coaches is also highly desirable. Review of credentials by senior leaders may include interviews.

COACH MIX

Match mix of internal and external coaches to the Lean Implementation phase. Organizations should employ both internal and external coaches in all three Lean Implementation Phases. Figure 4 depicts a recommended mix of external and internal coaches by Lean implementation phase. Both coach mix and roles should be modified as the implementation progresses from introduction to growth and sustainment phases.

- **Introduction Phase:** Focus on using highly experienced coaches that can provide quick and visible successes. Highly experienced coaches increase the probability

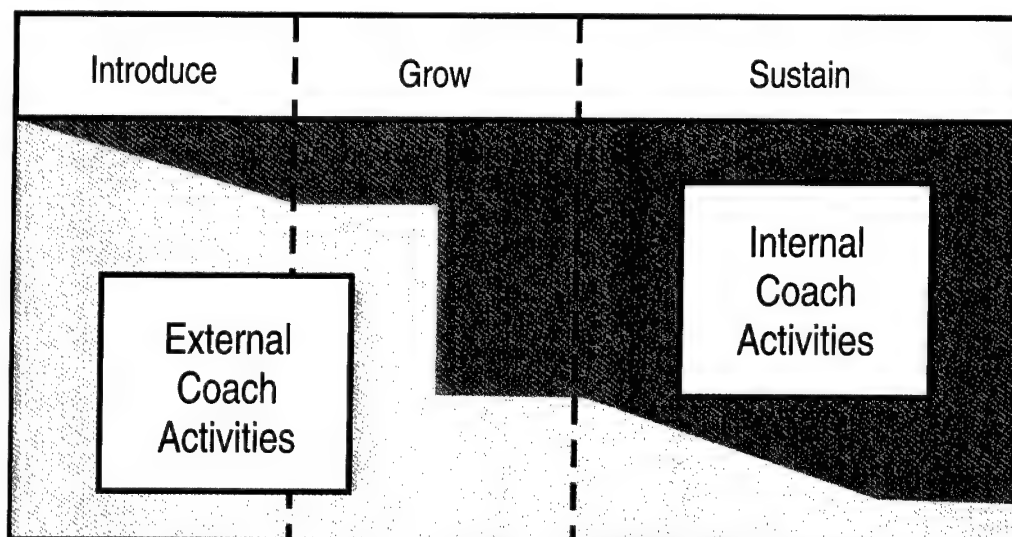


FIGURE 4. RECOMMENDED COACH MIX BY PHASE

of achieving early successes by ensuring events are properly scoped and planned and involve the correct people. Typically, highly experienced coaches do not reside in an organization that is just beginning to implement Lean; therefore, they must be obtained from external sources. Leverage the credibility of experienced coaches in having "been there and done that" in a similar organization to help overcome resistance implementing continuous process improvement.

- **Growth Phase:** Focus on using highly experienced coaches to build and develop an organization's internal coaching capability. During the early Growth Phase, the majority of will probably be external resources; however, in this phase, emphasize the capacity to train and develop coaches using internal resources.

"Typically, highly experienced coaches do not reside in an organization that is just beginning to implement Lean; therefore, they must be obtained from external sources."

- **Sustainment Phase:** Focus on conducting the majority of Lean activities using internal coaches but continue to employ external coaches to provide specialized support or an outside source of observation.

Assign coaches to the appropriate reporting chain based on the Lean Implementation Phase. During the Implementation Phase coaches should report directly to the corporate Lean champion (a senior executive or leader with a vested interest in the success of the Lean Transformation activities). During the growth and sustainment phases, maintain this reporting relationship as a training center for Lean experts within the parent organization, but move experienced coaches into the line organizations.

COACH TOOLS

Select a standard set of primary tools for coaches to use for planning, executing and evaluating routine process improvement events. This set of tools can be augmented with highly specialized tools such as Six Sigma statistical process control when required.

Each of the following primary coaching tools is a key ingredient to enable Lean teams to systematically achieve rapid and continuous process improvement.

Contract for Change

We, the Leadership, pledge to support the Lean transformation through the following actions:

- We will write and communicate a vision and strategy for the area that makes the Lean Transformation
- We shall appoint a "Core Team" that will figure out the specific approach to Lean for this area
- We shall participate in the Value Stream Analysis by attending the daily or weekly outbriefs, reaching consensus on major opportunities and improvement approaches and finally signing the contract for change
- We shall lead the improvement process through our work on the Steering committee and shall assign appropriate resources to ensure that the transformation is successful

_____	_____	_____
_____	_____	_____
_____	_____	_____

web.mit.edu/lean
Source: Raytheon

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FIGURE 5. SAMPLE CONTRACT FOR CHANGE

- **Planning tools:** Sign formal *Change Contracts* that describe desired outcomes, resources and specific roles (see Figure 5). The absence of change contracts in large organizations reduces the likelihood of implementations continuing beyond the introduction phase. After initial successes, organizations should employ more rigorous method to select and prioritize processes to apply Lean.

During event preparation, coaches worked closely with process managers and event leaders to develop a change contract. In medium and large organizations, coaches frequently used change contracts to clarify management expectations and secure commitment of needed resources.

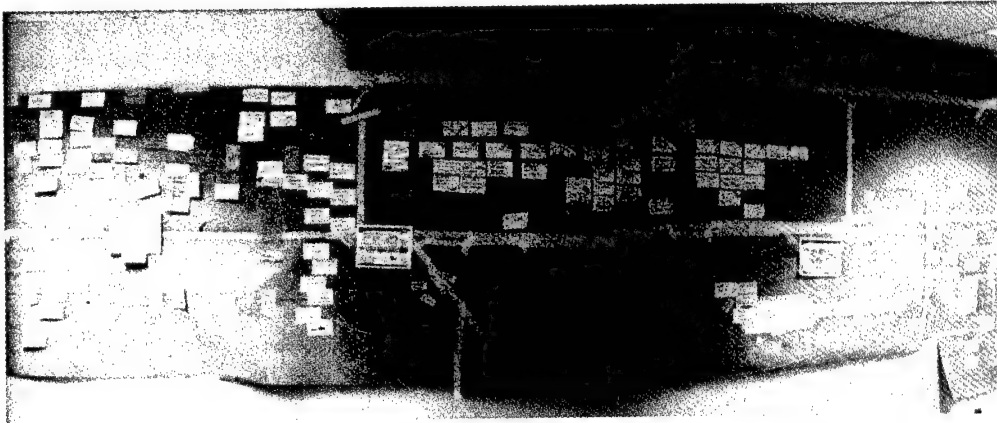


FIGURE 6. GLOBAL HAWK TIER I ENTERPRISE VSM

Change contracts served as charters for process improvement teams by clarifying expected outcomes, resources and establishing responsibilities for event leaders and participants. Change contracts in larger organizations were often signed by senior management to help communicate commitment to employees. In smaller organizations, the use of change contracts and other formal communication tools was less frequently observed.

- **Execution tools:** Use *Value Stream Mapping* (VSM) to help organizations make fact-based decisions throughout process improvement activities in each implementation phase. VSM can also help with selection and prioritization of process improvement events and more complex improvement projects. VSM is described in the book titled *Learning to See* by Mike Rother and John Shook (1999). The photo below (Figure 6) illustrates a Value Stream Map created by the Global Hawk System Program Office detailing their Tier I Enterprise.
- **Evaluation tools:** Assess benefits and costs of implementing Lean during all three phases. Larger organizations should establish a common method for determining Return On Investment (ROI) and cost savings for Lean events. While commercial industry may be able to link ROI directly to profit, DoD can compare investment with savings in resources including budget, manpower, material, and schedule.
- ROI was tracked in nearly all organizations implementing Lean. This was a consistent overarching objective for beginning and continuing a Lean journey. Investment cost was the cost hiring any external coaches plus the cost of time and materials for participants in an event from within the organization. The return was the amount that was booked to the bottom line (additional profit) as the result of the event. In most organizations, this bottom line saving was only the amount that could be booked during the fiscal year that the costs were incurred. Cost avoidances, both near- and long-term were tracked, but were not always credited as a true savings as a result of a Lean activity.

- External coaches were often measured based on return on investment. Expectations for booked savings were set for many internal coaches, but were not found to consistently be used as a measure of individual coach's performance. ROI was often used as an overall organization incentive, linking team rewards and recognition to the organization's contribution to the bottom line.

Communicate, Communicate, and Communicate with employees, managers, unions, and other process stakeholders. Medium and large size organizations have a stronger need to employ more sophisticated communication tools.

"Tailor Lean coach measurements to motivate key strategic outcomes."

The following example is a powerful communication tool, from a worldwide defense industry leader, that highlights leadership vision, workforce incentive, and action plan. The corporate Lean champion published a letter to employees that clearly described why the organization was implementing Lean and a timed phased strategy. The three-page color letter described 20 building blocks for changing the company's culture to continuous process improvement. Included were targets for full-time *Lean managers*, minimum annual participation in 5-day process improvement events, and Value Stream Mapping requirement for investments over \$250K. The letter was signed by the organizations Chief Operating Officer and mailed to the home of every employee.

COACH PERFORMANCE MEASURES

Measure key processes that support an organizations capability to implement Lean. For example, during growth phase, matching the number of coaches available to targets for number of process improvement events is critical. A generally employed rule of thumb is that 1 percent of an organization's workforce serves full-time Lean coaches during the transition from Growth to Sustainment. Other coach support processes that organizations may want to measure include selection/assignment, training/certification, employment/rotation, and retention/promotion of coaches. Tailor Lean coach measurements to motivate key strategic outcomes. Measurements should be continually reviewed and updated to ensure the outcomes being measured are motivating desired behaviors in the coaches, workforce, and managers being evaluated.

Assess coaches' effectiveness based upon a combination of measurable performance (such as planning and executing process improvement activities) and feedback from participants and organizational leaders. Supervisors of coaches should focus their assessment on those responsibilities relevant to the level of performance and on

expected outcomes of Lean activities. Coaches should be provided feedback on their effectiveness and value to the organization systematically following milestones, such as the completion of large complex projects.

CONCLUSION

We have highlighted the following nine important areas dealing with coaching strategies.

- **Establish** several levels of coaches with different degrees responsibilities.
- **Require** minimum Lean coaching credentials when hiring external coaches.
- **Select and Certify** internal coaches to an organizational standard.
- **Match** mix of internal and external coaches to the Lean Implementation phase.
- **Assign** coaches to appropriate reporting chain.
- **Select** a standard set of primary tools for coaches to use.
- **Communicate**, Communicate, and Communicate.
- **Measure** key processes that support Lean Implementation.
- **Assess** coaches' effectiveness.

As you continue through this special edition of the *Acquisition Review Journal*, bear in mind our **Number One Recommendation** that goes beyond coaching to encompass overall Lean Implementation Strategy: **Recognize** that implementing Lean methodology is an enabler for continuously improving organizational performance, not for achieving a one-time increase in performance. Organizations should not try to become Lean, but plan, execute, and evaluate Lean activities to continuously improve and provide stakeholders ever-increasing value.

DAU offers a variety of courses in our continuous learning center dealing with Lean and Six Sigma. These are available through the DAU Web site at www.dau.mil under continuous learning.

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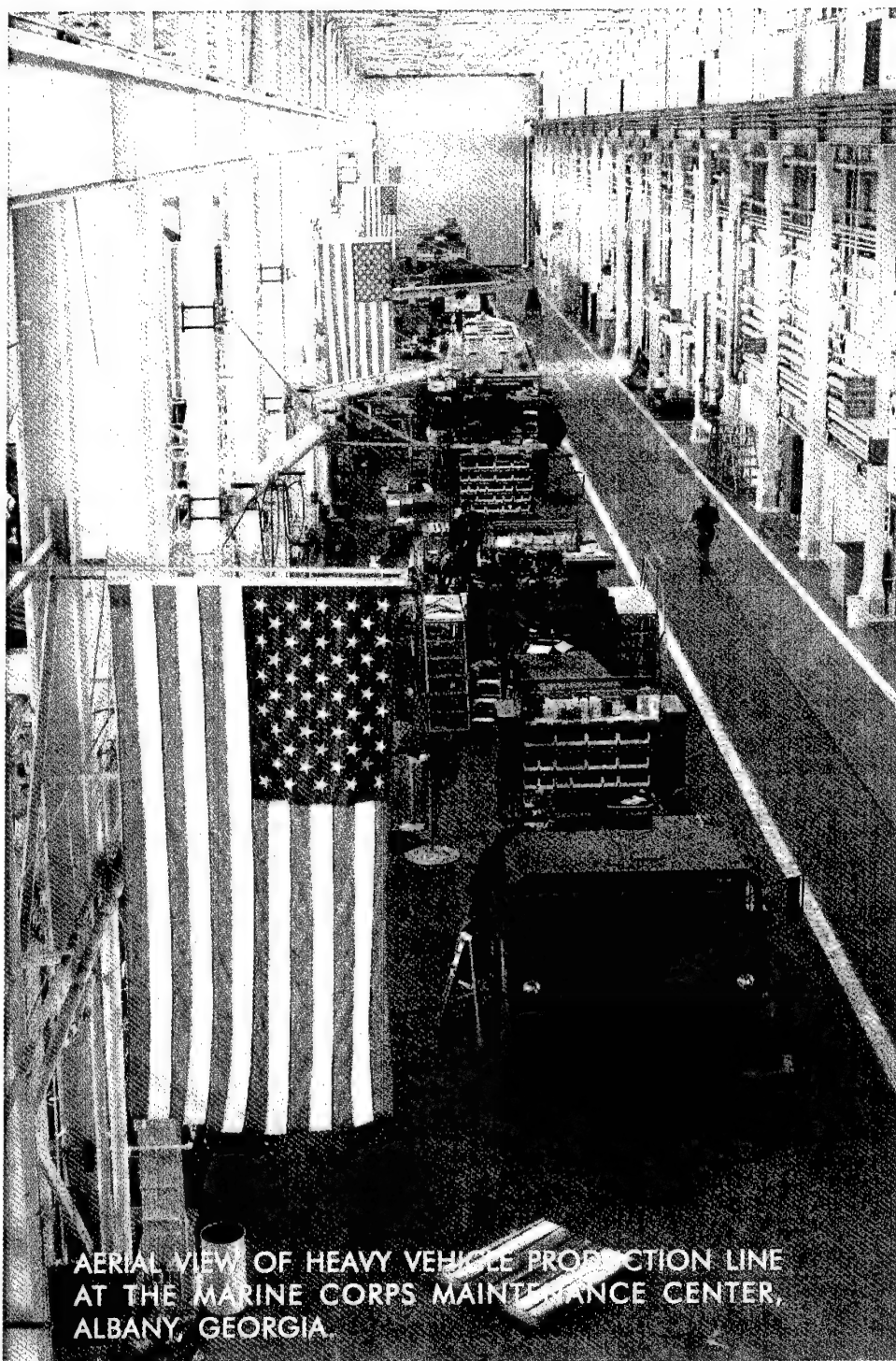
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AERIAL VIEW OF HEAVY VEHICLE PRODUCTION LINE
AT THE MARINE CORPS MAINTENANCE CENTER,
ALBANY, GEORGIA.

APPLYING THEORY OF CONSTRAINTS PRINCIPLES AND LEAN THINKING AT THE MARINE CORPS MAINTENANCE CENTER

MANDYAM SRINIVASAN, DARREN JONES, AND ALEX MILLER

The Maintenance Center for the Marine Corps Logistics Base, Albany, Georgia, launched a program in 2001 combining principles drawn from the Theory of Constraints and Lean thinking. The Center had been constantly plagued by apparent capacity shortages in virtually every department and additional manpower was being considered. An analysis using Theory of Constraints revealed that there was, in fact, more than adequate capacity to handle the workload. The perceived lack of capacity was due to policy constraints imposed on the Center as a result of a push scheduling mechanism. By implementing a pull system for scheduling repairs, the Center revealed capacity that had been masked. Today, the Center is ahead of, or on schedule, for 99 percent of the production lines where the Theory of Constraints principles have been implemented.

The Maintenance Center for the Marine Corps Logistics Base, Albany, Georgia, is responsible for the regeneration and reconstitution of the equipment required by the Marine Corps for combat readiness. The Center undertakes complex maintenance operations that include rebuilding equipment to original manufacturer's specifications. It repairs and overhauls a wide variety of products that include small arms, amphibious vehicles, light armored vehicles, fuel tankers, trucks, earthmoving equipment, and logistics vehicle systems.

In 2001, the Center was struggling to complete equipment repairs on time and was coping with an increasing backlog of work. Asking for *plus-ups* or additional time to complete the work had become a normal way of doing business. For instance, on the MK-48 program, entailing overhaul of a heavy-duty hauler for the Marine Corps, the Center was only producing five units a month against a demand of 10 per month. Customers were threatening to divert their orders to the private sector in search for better service.

At that time, scheduling of maintenance operations was based on a Manufacturing Resources Planning II (MRP-II) system that used a push system to load the resources at the Center based on anticipated customer demand. This was resulting in frequent rescheduling and expediting of critical items. The Center's management team reviewed alternate approaches to schedule production and picked one that drew on principles prescribed by the Theory of Constraints (TOC). It contracted with Vector Strategies¹ to implement a *Critical Chain* (Goldratt, 1997) pilot project on the MK-48 vehicle. The Critical Chain is an application of TOC principles specifically tailored for managing complex projects like programs for the overhaul of several major pieces of equipment. The pilot project proved successful and the Center began implementation of the Critical Chain plantwide in April 2002. Used in conjunction with concepts drawn from Lean thinking (Womack & Jones, 1996), this implementation has generated dramatic improvement in the Center's performance.

THE THEORY OF CONSTRAINTS AND THE CRITICAL CHAIN

In the 1980s, Goldratt and Cox (1992) presented Theory of Constraints as a methodology for managing production planning and scheduling. The Theory of Constraints is based on the principle that the goal of any economic enterprise is to make money, now and in the future, and that a system's constraints determine its capacity to make money. Goldratt prescribed a five step *focusing* process to enable a process of ongoing improvement: a) identify the system's constraint(s), b) decide how to exploit the system's constraint(s), c) subordinate everything else to the decision in step b, d) elevate the system's constraint(s), e) return to step 1 if the system's constraints were changed.

In 1997, Goldratt introduced the Critical Chain methodology to apply Theory of Constraints concepts to manage large projects. Program Evaluation and Review Technique (PERT) is probably the single most popular project management tool, and it has been in use for decades. PERT provides the means for identifying the *critical path*, which is the major determinant of the project completion date since the critical path is the single longest chain of linked events embedded in the overall project. The Critical Chain methodology expands on this notion of the critical path and presents a means of determining where buffers should be placed to prevent unplanned disruptions from delaying the project completion.

Figure 1 presents a simple example that illustrates the Critical Chain methodology. This figure represents a project that has four sets of activities that must be completed before a synchronization operation, represented by C4 in the figure, can be completed.

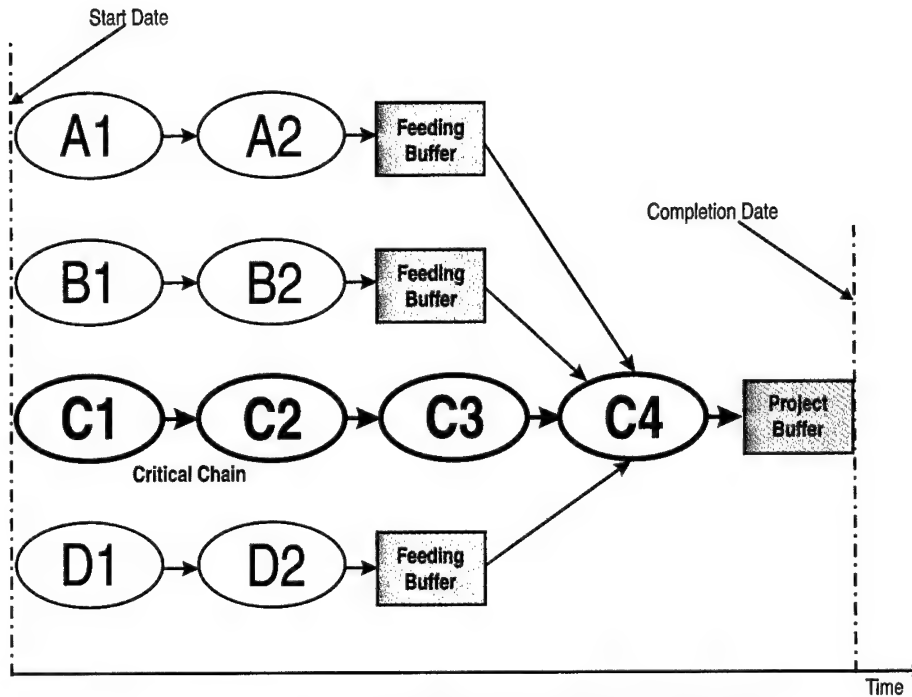


FIGURE 1. THE CRITICAL CHAIN CONCEPT

The synchronization operation could be one of a variety of operations. For instance, in a manufacturing setting it could be an assembly operation, and in a project management setting it could represent the commissioning operation.

PROJECT BUFFERS, FEEDING BUFFERS, AND CAPACITY BUFFERS

The analyst uses historical data to obtain an estimate of the average time for each activity. These are co-mingled to compute the average time it takes each series of activities that must be completed before the assembly operation can begin.

Suppose an analysis reveals that the series of activities with the longest average time is C1-C2-C3. This determines the critical chain² that must be monitored the most closely, since any slippage of these items will cause slippage of the overall project. The activities along the critical chain, namely, C1, C2, C3, and C4 are termed critical activities. Activities not on the critical chain are not critical items—they can slip some and not have the overall project slip because their completion takes less time than the completion of the critical chain.

The estimate for the project duration (the lead time) is now obtained as the sum of the average activity times for the critical activities, plus a safety time, termed the *Project Buffer*. This buffers against any variation in the completion times of activities times along the critical chain. The Project Buffer is based on the variance of the total activity time. An overall measure of this variance is obtained simply by summing up the variance (the square of the standard deviation) for each activity.

In addition, for each non-critical activity that feeds a critical activity, a *Feeding Buffer* is placed between the non-critical activity and the critical activity, as illustrated in Figure 1. The Feeding Buffers are determined in a manner similar to the way the Project Buffer is calculated. It must be noted that the Project Buffer and the Feeding Buffers are time buffers and not inventory buffers. That is, variation is *buffered by capacity, rather than inventory*.

With properly sized buffers, the activity along the critical chain that requires inputs from non-critical chain activities has a better chance of being able to start as soon as its predecessor task on the critical chain is complete. This means average throughput time should be reduced. It also means less inventory will be tied up in the system of activities overall.

IMPLEMENTING THE CRITICAL CHAIN AT THE MAINTENANCE CENTER

The overhaul process at the Center starts with disassembly of each vehicle to determine its *work scope*, the amount and nature of the work to be done on that product. The work scope also indicates which parts can be repaired and which parts need to be replaced. Parts that require repair are routed through a series of support shops that include cleaning, blasting, painting, machining, body work, weapons work, and so on. Parts that need replacement are either replaced from existing spare-parts stock or ordered from an external source. Some of these parts are difficult to procure if they are not in stock for a variety of reasons, including obsolescence.

"Manufacturing Resources Planning (MRP) is a widely used computer modeling technique that incorporates part lead times and demand forecasts into production plans and schedules."

THE MRP II SCHEDULING SYSTEM

Manufacturing Resources Planning (MRP) is a widely used computer modeling technique that incorporates part lead times and demand forecasts into production plans and schedules. (MRP II is the second generation of such models meant to facilitate just in time production.) At the time the pilot project began, scheduling was based on an MRP II push system. It was a push system in that products were introduced into the shops without regard to the status of the resources dedicated to the repair activities. This led to false starts and delays, increased inventories, and lowered throughput.

Another problem that the MRP II scheduling practice created was that it resulted in multitasking. Multitasking here refers to the fact that some projects (repair jobs) may have activities that require a common resource (employee or machine). When these resources are required to attend to more than one project, the resources are moved between projects even before they complete all the processing on a given project and hand it over to the next activity in the sequence. As a result, each one of the projects involved tends to take more time than if they were completed one-at-a-time from start to finish.

The problem of multitasking at the Center arose as follows. Given the perception that many units had to be disassembled to get parts for units in assembly, it was also believed that disassembled parts should be sent immediately to the support shops, to have as much time as possible to move through the repair cycle. Consequently, many of the resources were subject to multitasking. This is a problem that the Critical Chain is designed to address.

"The root cause of the consistent shortfalls and high inventory levels seemed to be the scheduling system in place that was pushing products out to the shop floor without regard for the status of the resources."

THE BOTTLENECK

As a first step toward applying TOC, the Center's management sought input from throughout the organization on where bottlenecks were believed to be a serious problem limiting output. Opinions varied as to what were and were not bottleneck activities, but every major activity in the Center was believed to be an important bottleneck by at least someone in the facility.

In applying the Theory of Constraints to address the Center's problems, the main shop, where the main products were first disassembled and subsequently reassembled, and the support shops (cleaning, repair, etc.), were modeled as the Critical Chain. The Critical Chain analysis of the data collected revealed that, contrary to everyone's opinion, the facility had more than enough of capacity to carry out the activities required to meet the demand for repair and overhaul of 10 MK-48s per month. The root cause of the consistent shortfalls and high inventory levels seemed to be the scheduling system in place that was pushing products out to the shop floor without regard for the status of the resources. The bottleneck was thus *not a physical resource constraint*. Rather, it was a *policy constraint* introduced by the scheduling process. This discovery allowed Vector Strategies to use a *Simplified Drum-Buffer-Rope*

(S-DBR) technique to model and schedule the activities in the shops that processed components removed from the main products.

THE SIMPLIFIED DRUM-BUFFER-ROPE TECHNIQUE

One of the tools used by TOC to manage production is the Drum-Buffer-Rope (DBR) system. The DBR is a pull-scheduling system that releases material based on a signal from the bottleneck. The traditional DBR model releases orders into the production process such that it synchronizes with the production rate of the least capable resource in the process. This least capable resource is referred to as the capacity-constrained-resource (CCR). If the CCR works at a rate that is less than the rate of output demanded by the customer, then it is the bottleneck. (Otherwise, the external demand rate, *the market*, is the bottleneck.)

In the standard DBR model, the production rate of the CCR is referred to as the *drum*, and the drum beat (production rate of the CCR) paces production for the system. The *rope* in DBR refers to the mechanism that releases work into the production process. The rope is essentially a communication device that ensures that raw material is not introduced into the shop floor at a rate faster than the CCR can handle. If the CCR is not the bottleneck, then the rope ensures that the raw material is not introduced into the shop floor at a rate faster than the customer demand rate. Finally, to prevent the CCR from ever having to wait for work if it becomes free (protect the CCR from being *starved*), a time *buffer* is placed ahead of the CCR to ensure that jobs arrive at the CCR well in advance before they are scheduled for processing at the CCR. Another buffer, called the shipping buffer, protects the situation where the customer's order might be delayed. The standard DBR model is presented in Figure 2.

The standard DBR model requires specialized DBR software to implement it. For enterprises that already have common MRP systems in place, an alternate technique known as the *Simplified* Drum-Buffer-Rope (S-DBR) model can be used, when the enterprise is not constrained by any internal resource (the situation at the Center as revealed by the initial Critical Chain analysis). The drum in S-DBR is based on firm orders. As orders come in, a quick check is made on the total load on the CCR. If the CCR is not too heavily loaded, the order is accepted and released into the shop floor for processing. The only buffer maintained is the shipping buffer. The rope is no longer tied to the CCR schedule. Instead, the material release schedule is directly generated by firm orders received. See Figure 3.

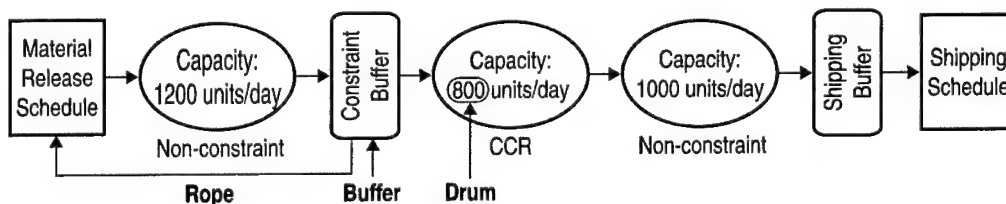


FIGURE 2. THE TRADITIONAL DRUM-BUFFER-ROPE MODEL

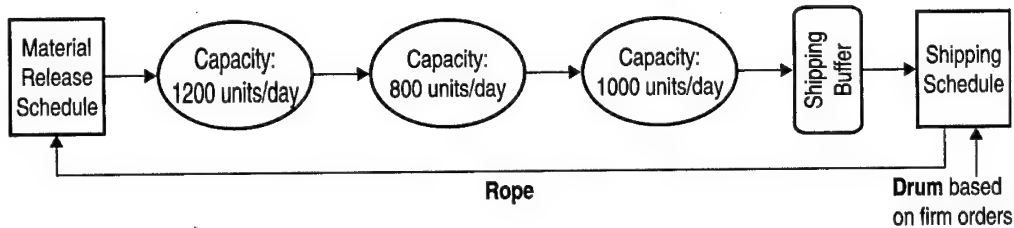


FIGURE 3. THE SIMPLIFIED DRUM-BUFFER-ROPE MODEL

The S-DBR model has some advantages. It does not require any specialized software, and this can be a significant benefit for enterprises that might be unwilling or unable to invest in specialized DBR software (Schrage & Dettmer, 2000). Another advantage of the S-DBR approach is that it does not have to require two buffers, but needs just one. Finally, the S-DBR approach is more focused on market demand and ties the organization to its customers more directly.

RESULTS FROM THE IMPLEMENTATION OF CRITICAL CHAIN AND S-DBR

The Center was able to use an S-DBR approach to scheduling in conjunction with the existing MRP II business system as described above. Only the Critical Chain portion of their solution required additional software.³ The MRP II system that was used for scheduling now facilitates the S-DBR schedules. The MRP II database also stores data on lead times for items supplied by vendors.

Table 1 presents the results of implementing the Critical Chain on the MK-48 and the LAV-25, the landing assault vehicle that was the focus of the second Theory of Constraints/Critical Chain implementation effort.

As Table 1 indicates, repair cycle times for the MK-48 were reduced by a factor of 3, from an average of 167 days to an average of 58 days. For the LAV-25, the corresponding figures were 212 days and 119 days, before and after. The

TABLE 1. RESULTS ON THE MK-48 AND LAV-25 LINES

Line	Repair Cycle Time (Days)			Units in WIP/Monthly Demand		
	Before	TOC/CC*	After	Before	TOC/CC*	After
MK48	167	52	58	5.5	1.75	1.4
LAV-25	212	99	119	4.3	3.2	3.1

*Formulated cycle times and work in progress based on analysis of Theory of Constraints and Critical Chain.

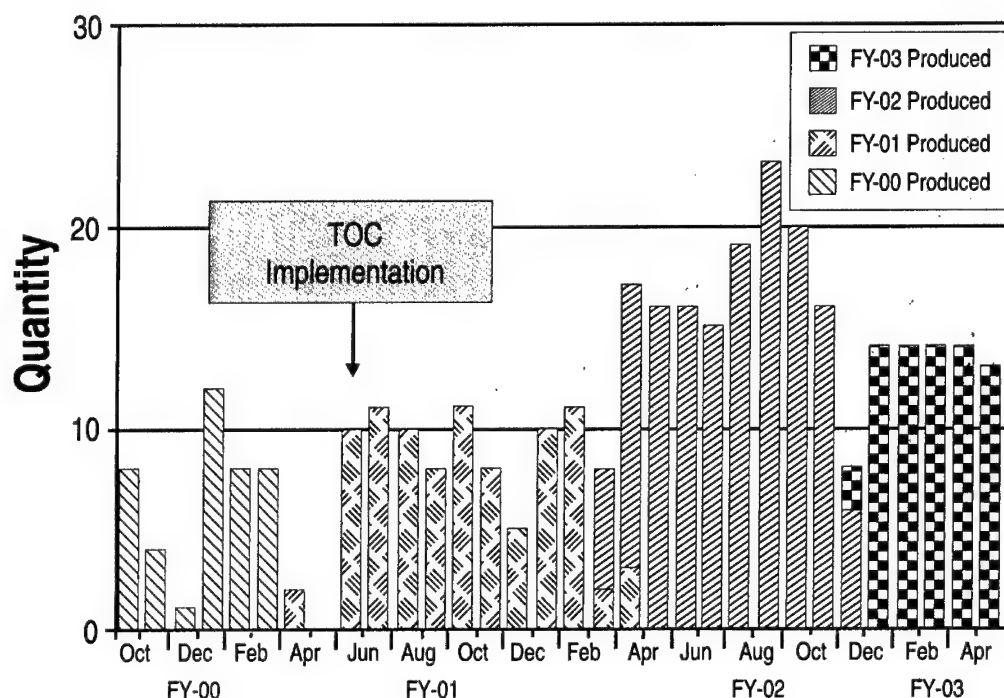


FIGURE 4. MK-48 MONTHLY OUTPUT

work in process levels (relative to demand) was also reduced significantly, as shown in the table. Other products showed similar reductions in cycle times and work in process.

The cost to repair products also went down by 25 to 30 percent, mainly because the reduction in delays resulted in more throughput without any increase in the cost of repair. All the product lines are now 99 percent on schedule to customer requirements. Figure 4 shows the increase in output realized on the MK-48 line. The capacity for the MK-48 line is now much more flexible, and can work with a rate of anywhere between 10 units per month to as high as 23 units per month, as indicated by the figure.

COMBINING LEAN THINKING WITH TOC PRINCIPLES

The principles in Theory of Constraints can be used in conjunction with Lean thinking to leverage even more benefits for the enterprise. Like Theory of Constraints, Lean thinking is a means of enabling a growth strategy.⁴ Unlike Theory of Constraints, which primarily focuses on the bottleneck, Lean thinking is focused on reducing waste at all levels and in the process of doing so, it uncovers additional capacity that could be deployed for further growth.

At the Maintenance Center, a corporate plan was developed for implementation of Lean thinking and a Lean team was set up. Some of the results of the

Lean efforts resulted in the Center being subject to a 6-S activity and a reengineering of the supply warehouse. (6-S is a set of practices aimed at cleaning and organizing a workplace to improve operations and safety.) The 6-S activity resulted in a significant increase in available shop floor space. Hundreds of man-hours associated with the testing and repair of cables on the Assault Amphibious Vehicle (AAV) and Light Armored Vehicle (LAV) family of vehicles were saved. Tools in excess of \$200,000 were turned in for redistribution and future use. The process flows in production work centers were streamlined. Another major benefit from the convergence of Lean thinking and TOC was that it resulted in increased morale for the employees of the Center. The workplace is cleaner, less cluttered, and safer. The Center has become extremely flexible and better positioned to meet its responsibilities for regeneration and reconstitution of critical supplies.

CONCLUSION

Managing a maintenance, repair, and overhaul (MRO) facility is a more challenging task than managing most manufacturing facilities because of the high degree of uncertainty that prevails in repair operations. Unlike a typical flow shop manufacturing setting where the enterprise knows the sequence of operations required to complete the finished product, the MRO facility is very much like a pure job shop facility. In the MRO facility, the work scope of a product that arrives at the facility is not known unless the product is disassembled and inspected. There is a tremendous variation in the work scope even for the same type of product, such as the MK-48, and it is difficult to accurately predict the percentage of parts that must be replaced and the percentage of parts that should be repaired. To add to the complexity, the original manufacturer may no longer produce the parts that have to be replaced.

"Managing a maintenance, repair, and overhaul (MRO) facility is a more challenging task than managing most manufacturing facilities because of the high degree of uncertainty that prevails in repair operations."

As Vector Strategies observed, the magnitude of culture change was greatest in the support shops through which disassembled parts are routed for repair. Holding disassembled parts for release caused great fear among the workforce, and resistance was substantial. This aspect of the implementation was the last

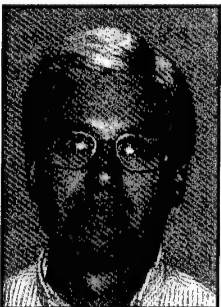
part of the culture change accepted and accomplished by the Maintenance Center. But as they saw significant improvement with every other aspect of the implementation, they gained the courage to move forward.

The work carried out to date has made the Albany Maintenance Center a showcase of world-class overhaul and repair performance. Weekly tours are conducted, hosting officers and executives from government and private overhaul and repair operations. The Center's Web site (www.ala.usmc.mil/maintctr) and monthly reports prominently features Theory of Constraints and Lean applications. Although the Center has achieved significant successes, Theory of Constraints and Lean thinking are a process of ongoing improvement. One instance of improvement that may be a candidate for future consideration is the manner in which products are repaired. Currently, the mode of operation is to employ a station-build. The Center could consider operating the repair facility as a flow-cell using a moving line. This is a subject of future research.



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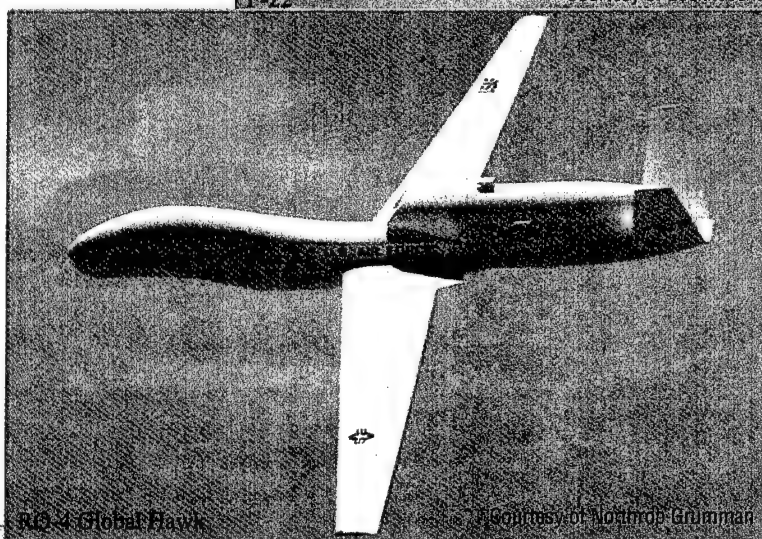
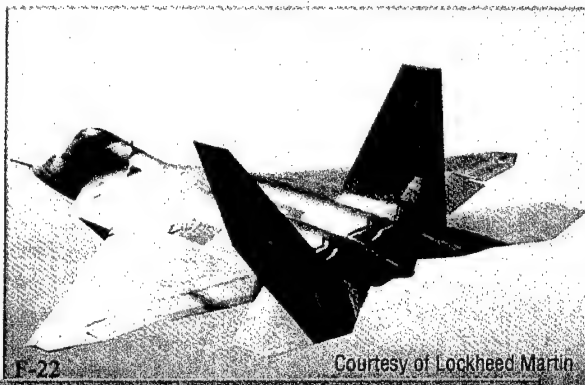
AUTHOR BIOGRAPHIES

ENDNOTES

1. <http://www.vectorstrategies.com>
2. We will use the lower case (critical chain) to identify the set of activities that must be most closely monitored and the upper case (Critical Chain) to identify the methodology.
3. This software, *Concerto*, was procured from Realization Technologies.
4. Sprovieri interview with Tom Greenwood.

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LEAN NOW—USING A RESEARCH COMMUNITY TO UNDERSTAND CHANGE IN THE ACQUISITION ENTERPRISE

ERIC REBENTISCH, PH.D. AND MAJ RONALD JOBO, USAF

Members of the Lean Aerospace Initiative (LAI) consortium have joined to pool experience and expertise to accelerate the adoption of Lean practices in military acquisition through an initiative called *Lean Now*. Lean Now has demonstrated that the concept of industry and government teaming for focused interventions can produce savings and accelerate change in the acquisition process. It also represents a systematic change method that lends itself to data collection and theory development. This paper outlines some of the findings to date, as well as implications for using such a model for research on the military acquisition system.

Acquisition system improvement (the term *acquisition reform* is also used) has been an imperative since the earliest days of the U.S. military. In the 20th century, several movements, often involving expert commissions or panels, sought to improve the performance, relevance, and adaptability of an increasingly large, complex, and bureaucratic system (McKinney, Gholz, & Sapolsky, 1994). Most of these efforts used a top-down approach to change. Many other, less visible attempts to improve the acquisition system have used a bottom-up approach, focusing at the level of practitioner in an attempt to foster systemic change through the diffusion of best practice. This paper is about one such initiative, and how it is lending itself to research and insights about improvement processes in the complex government acquisition system.

In August 2002, the Lean Aerospace Initiative (LAI) Executive Board committed to help the government apply lessons learned from Lean implementation within its own operations. The industry partners of LAI had already started on the path to Lean in the mid-1990s and were making significant improvements, mostly in production and manufacturing operations. The purpose of the Lean Now initiative was to accelerate transformation of the total government/industry enterprise by:

- Eliminating barriers that impede progress.
- Focusing on the interface processes between government and industry.
- Using the LAI venue to facilitate government/industry collaboration and teamwork.
- Leveraging the collective knowledge and efforts of government and industry.

In October 2002, candidate government/industry processes and programs that exemplified them were selected. They were the F/A-22 Test and Evaluation process, the F-16 Contract Closeout process, and the Global Hawk Evolutionary Acquisition processes. The prototypes were to prove if the Lean Now concept of focusing on government/industry interfaces was feasible. It was hoped that the results and lessons learned from the prototype programs could be applied to other Air Force programs and possibly throughout the Department of Defense (DoD).

***"Action research is focused on understanding
and creating knowledge about
social interventions and change."***

Lean Now fully availed itself of the resources of the LAI consortium. It was truly a partnership between government, industry, and academia. Through the LAI venue, Massachusetts Institute of Technology (MIT) provided the knowledge and research-based tools; the industry partners provided the practical experiences of its best Lean Subject Matter Experts (SMEs) to kick-start and accelerate the government's transformation. Industry agreed to provide SMEs for the first year of Lean Now to train and mentor the prototype programs. This would give the Air Force a chance to learn from industry experts, while building its own infrastructure of Air Force Lean SMEs. To help the Air Force become self-sufficient in Lean, MIT and the LAI industry partners are also developing an Air Force SME training course.

In addition to being a vehicle for accelerating the adoption of Lean in government acquisition processes, Lean Now represents an ideal opportunity to pursue research in the style of action research (Argyris, Putnam, & Smith, 1985). Action research is

focused on understanding and creating knowledge about social interventions and change. If successful, the knowledge it produces can be used to aid future implementation activities, to advance theory about change, and to better understand the nature of systems being changed to more thoughtfully construct models of alternative future states. This approach is especially cogent to complex systems such as the military acquisition process, with its multiple interdependent stakeholders.

While Lean Now began with a push to jump-start the adoption of Lean principles and practices in the U.S. Air Force, it is beginning to yield new insights not only into change processes in the acquisition system, but also the structure and behavior of the system itself. Moreover, because it is proceeding using a relatively structured process, it lends itself well to systematic study. This paper will discuss early findings from Lean Now (this report documents only the beginning of what could eventually be a multi-year experiment). It will finish by discussing its implications for future acquisition research activities.

INTERVENTION METHOD

A common method for intervening in a Lean Now engagement is emerging based on the combined experience of the LAI SMEs and its application to date. This method has three distinct phases: (1) Set-up Phase, (2) Planning Phase, and (3) Execution and Follow-through. Within each phase are distinct steps that must occur in order for the Lean initiative to be successful. Figure 1 presents the three phases and their respective steps.

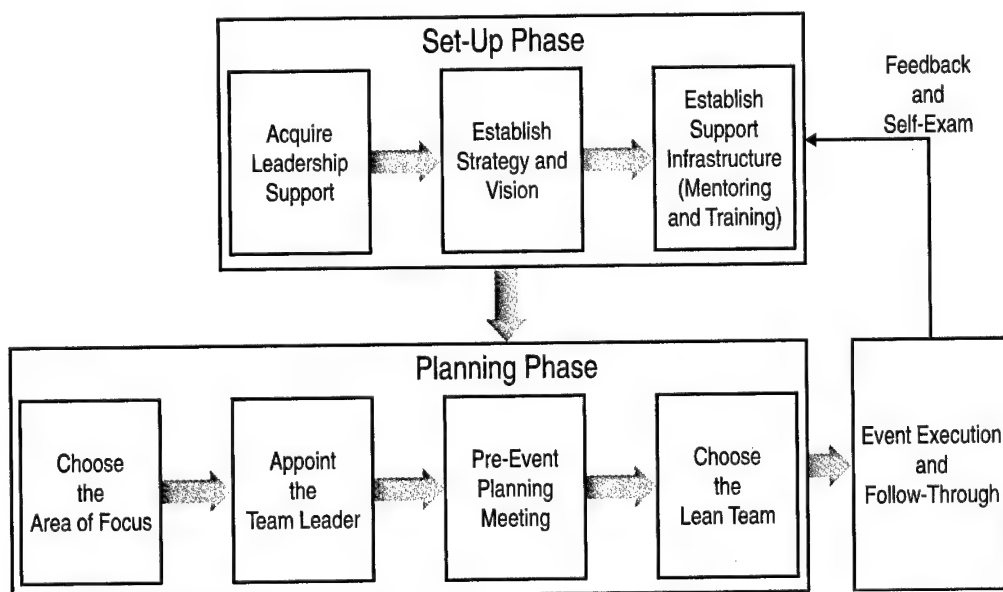


FIGURE 1. THE LEAN NOW ENGAGEMENT PROCESS

The first step in the Set-up Phase involves acquiring leadership support, setting the vision, strategy, and goals of the initiative, and ensuring the organization has the infrastructure to support the initiatives. This infrastructure includes having a Lean SME and a Lean training curriculum. The Lean Now projects relied on LAI's industry partners for their support infrastructure.

The Planning Phase comes next. The first step is to choose the area of focus. Several methods were used: (1) pick the program with the greatest sense of urgency, (2) use a decision matrix, (3) use the value stream map (VSM), or (4) have someone else choose it for you. The next step is to choose the initiative's team leader. The team leader must be knowledgeable and experienced in the processes to be examined, a good communicator, open to new ideas, and possess the ability to juggle many things at once. Once the team leader is chosen, he or she meets with the Lean Subject Matter Expert to discuss the project, its goals, resource availability and constraints, and any possible barriers to implementation. They also plan the Lean event, including the team training requirements and the Lean methods and tools to be used during the event. They then choose the Lean team. All stakeholders must have a representative on the team. In order to make the team effective, each team member must have a practical experience in the process to be examined and have the backing of his or her leadership.

"As the results from the Lean initiative begin to materialize, it is important to apply any feedback or lessons to continuously improve the process."

After these steps are complete, it is possible to hold a Lean event. Depending on the event, the Lean SME will facilitate the team's use of the appropriate Lean tools and methodologies. After the Lean event, the team leader must ensure each member of the team follows through on his or her assigned action items. The team leader is also responsible for communicating the status of the initiative to the organization or enterprise leadership. As the results from the Lean initiative begin to materialize, it is important to apply any feedback or lessons to continuously improve the process. These lessons are also continuously collected, documented, and shared throughout the organization and enterprise.

Because the process for intervention is becoming standardized, the findings of the Lean Now events lend themselves well to systematic empirical study. With the foundation of a standard intervention method, variables can be manipulated to produce research designs that create knowledge and advance theory about system change.

FINDINGS

Summaries of each of the three prototype projects presented below provide a context for Lean Now and its activities. A set of general observations describes some of the key lessons learned and concludes this section.

F/A-22

Lean Now was proposed as a way to help the F-22 program in meeting its cost, schedule, and performance expectations, specifically involving the test and evaluation process. The Operational Flight Program (OFP) Preparation and Load process at the F/A-22 Combined Test Force (CTF) at Edwards Air Force Base (AFB) was selected by the F-22 Enterprise Lean Team. The OFP is the software that runs the systems on the F/A-22 and is highly dependent on the hardware configuration of the aircraft. The test aircraft are configured according to the test they have to perform. As testing progresses, new OFPs and new hardware configurations are generated, with a resulting challenge of keeping track of the many OFP versions/aircraft configurations and quickly reconfiguring test aircraft as changes arise. This challenge prevented the F/A-22 test program from generating test sorties in a timely fashion.

"The F/A-22 CTF was so compelled by the results of the OFP Prep and Load Lean project that they held another VSM event that identified 20 projects for the F/A-22 enterprise."

A team assembled at the F/A-22's Combined Test Force at Edwards AFB and first did a VSM of the existing OFP Prep and Load process and identified many issues that caused delays and rework. By the end of the week, the team articulated the desired end state of their OFP process and generated 144 improvement suggestions to help get to this future state. The team returned to their respective jobs to start implementing the changes identified during the VSM exercise. Prior to Lean Now, the OFP Prep and Load process took between 60 and 90 days. The results of the initial suggestions lowered the time to 3 to 4 weeks. Through continuous improvement, the OFP Prep and Load time is now approximately 7 hours.

The F/A-22 CTF was so compelled by the results of the OFP Prep and Load Lean project that they held another VSM event that identified 20 projects for the F/A-22 enterprise. These projects included eliminating multiple identification numbers for the same part, better managing test asset and pilot availability to ensure fewer deviations from the test plan, reducing finishes rework after flightline activities, and aligning budgets with requirements. Each project was assigned to the stakeholder process owner,

with an accompanying target completion date, and all are underway. As they work on these initiatives and identify waste, they find that they are identifying further areas requiring improvement, with some of the original initiatives generating three or four additional initiatives.

GLOBAL HAWK

The Global Hawk is the U.S. Air Force's long range, unmanned, intelligence, surveillance, and reconnaissance (ISR) platform. The program has a very aggressive *spiral acquisition* approach that challenged its development schedule because of the time it took to put a new spiral on contract. One of the Lean Now project's foci was to reduce the cost and lead time of the platform's subsystems, while another was decreasing the time to put a new capability spiral on contract.

The Global Hawk System Program/Project Office (SPO), Northrop Grumman, and Raytheon chose to tackle the Integrated Sensor Suite (ISS) in the first event. The ISS costs as much as the airframe and engines and has an 18-month lead time. The ISS Lean team completed a value stream map of the current ISS production process from request for proposal to first flight. Through the use of the VSM, the team established a plan that increased the production capacity from 3 per year to 6 per year, with a savings of \$2 million per ISS. Other potential opportunities for further decreasing cost and production time were found, which the team is currently exploring.

"The Global Hawk is the U.S. Air Force's long range, unmanned, intelligence, surveillance, and reconnaissance (ISR) platform."

A value stream map of the Integrated Communications Suite (ICS) helped identify opportunities to eliminate \$3.6 million of specialized test equipment and reduce lead time between 2 to 3 months. This was done by eliminating unnecessary specialized test equipment and identifying the need for other test equipment to accelerate the transition to production. It also identified possible lifecycle cost savings from using common modules and open systems architecture. Finally, value stream mapping of the Alpha Contracting process identified means to reduce the average time to produce a formal proposal from 265 man-days to 166 man-days.

The Global Hawk team continues its work on the ISS, ICS, and Alpha Contracting projects to further reduce cost and cycle time. It is finding that in order to make further headway, stakeholders such as Air Force Materiel Command, the Defense Finance Accounting Service, and the Defense Contract Management Agency must also be involved in the process.

F-16

The F-16 Lean Now team chose to focus on the Contract Closeout process, and specifically, inactive contracts. Contract closeout is the activities associated with reconciling the terms of the contract with the products and services delivered. The process is long (on the order of 8 to 10 years) and is very resource intensive. There is currently a backlog of approximately 1,200 Lockheed Martin inactive contracts for the F-16, with some dating back to the late 1970s. The goal of the F-16 Lean Now initiative was to reduce the cycle time to close a contract, increase the efficiency and reduce the resources required, and to eliminate the backlog of contracts that are currently inactive yet remain open.

"Contract closeout is the activities associated with reconciling the terms of the contract with the products and services delivered."

Even before the Lean Now initiative, the F-16 program had been working to close the backlog of inactive contracts and made significant gains in the Contract Closeout process. By the end of the four-day value-stream mapping event, the team realized that their proposed changes did little to reduce the time to closeout contracts. Process stakeholders at a higher level would have to become engaged.

Based on the first event, the Lean Now SMEs held another Contract Closeout event involving higher-level stakeholders that identified 12 viable initiatives, including establishing one Defense Finance and Accounting Service (DFAS) point of contact for the contract, expand Defense Contract Management Agency (DCMA) Q Final authority to cover fixed-price contracts, automation of work order generation process for contracts entering an annual audit phase, and aligning subcontractor contracts actions with contractor contract actions. If all 12 initiatives can be implemented successfully, the projected minimum cost avoidance to the F-16 program is \$2.4 million and an estimated cycle time reduction between 3 to 7 years. Several of them have been completed or are underway with some dovetailing work by senior leadership at the U.S. Air Force Aeronautical System Center, the DoD, or Congress.

GENERAL OBSERVATIONS

Lean Now's first spiral of programs proved the feasibility of a government-industry focus on process interfaces to create useful change. Each of the projects was success-

oriented; they were not likely to fail to produce positive results. Consequently, it is challenging to identify clear *success factors* leading to superior outcomes. Nevertheless, there was sufficient variation in how each of the projects proceeded compared with the standard process and in the outcomes to note a few key differences. A more detailed exploration of those observations can be found in the report by Jobo (2003). Of distinction among the many observations that emerged from the experience with the prototype projects were characteristics of both leadership and of the teams (shown in Table 1).

The first three Lean Now prototypes had support from very senior Air Force leaders. This allowed the enterprise leaders and Lean teams the opportunity to take risks and try options never before considered—they knew it was okay to make mistakes. At more tactical levels, it was important that local leaders provided clear direction for how the Lean project fit into strategic plans and would help the organization achieve its strategic objectives. Lacking that, teams were more likely to *have Lean events* without the necessary follow-through to achieve compelling changes to enterprise processes. As such, leadership played a key role in follow-up to ensure the team stayed motivated and completed action items resulting from the Lean activities. While part of this involved the specific actions of the leaders of the initiative, it also played out in the degree to which the team was able and had the resources to manage or change the processes within their collective control.

The importance of team composition was demonstrated on multiple occasions. It was important that stakeholders in the process be represented, and their values defined so that they could articulate clear objectives to focus their efforts. The VSM exercises were important to not only identify underlying process flows, but also to identify the interdependencies among stakeholders that when dysfunctional could lead to ineffective communication, hand-offs, or other sources of waste in the system. The act of value stream mapping was in many cases a key communication process for uniting these groups that otherwise had not previously met.

TABLE 1. BEHAVIOR FOR LEADERSHIP AND TEAM MEMBERS FOR SUCCESSFUL LEAN INTERVENTIONS

Leadership Involvement for Successful Lean Implementation	<ul style="list-style-type: none"> • Long-term thinking and strategic vision. • Provides strategic direction and objectives. • Provides momentum for change. • Provides resources for implementation. • Provides the credibility and consistency of method for change. • Empowers project teams.
Team Involvement for Successful Lean Implementation	<ul style="list-style-type: none"> • Members must possess the correct level of authority for the given event. • Members must possess the correct level of expertise for the given event. • Members must be open to new possibilities.

Whatever the final outcome of these first three Lean Now prototypes, it is safe to say Lean has made an impact on the F/A-22, Global Hawk, and F-16 programs. The real value of Lean Now to date may not be the discrete results achieved as much as it represents the first steps in the building of an infrastructure for change and transformation. This effect is seen in the number of additional improvement events that were spawned by the initial interventions, and by the skeptical participants who through the process became dedicated advocates.

RESEARCH IMPLICATIONS

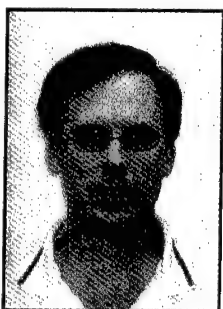
To date, the primary efforts associated with Lean Now have involved creating and standardizing the intervention method, deploying the SMEs and conducting the actual events, and documenting the outcomes. In a sense, Lean Now might represent the earliest phases of an action research program. More complete documentation of results and presentation to academic and peer research audiences lies ahead, as well as more active involvement in defining the subjects and content of the interventions. Even though it is in its early days, Lean Now already represents a significant investment of time and resources on the part of several individuals and organizations. From a research standpoint, this implies a significant *up-front* investment in creating the research context prior to doing the research. In this regard, undertaking a project such as Lean Now may not be appropriate or feasible for all researchers. Nevertheless, because of the unique nature of this activity, it represents a compelling venture for study that has already begun to produce results consistent with the aims of traditional action research.

"To date, the primary efforts associated with Lean Now have involved creating and standardizing the intervention method, deploying the SMEs and conducting the actual events, and documenting the outcomes."

Lean Now has captured knowledge from a variety of sources on how to have successful organizational change intervention, and demonstrated its successful diffusion in a variety of contexts. Additional facilitators have been trained using these materials, and the number of active Lean Now projects has increased dramatically, most importantly in the form of initiatives spawned from the initial events and based on local demand.

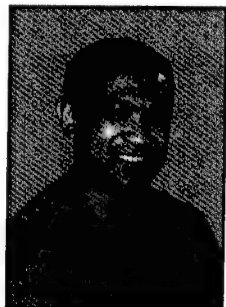
From a theory development perspective, the preliminary nature of Lean Now means that there are still many more questions than answers. Lean Now events have grappled directly with the challenge of scalability—whether a technique with origins in

group-level interventions can work successfully in enterprises spanning multiple organizational boundaries. An important next step might be, for instance, to manipulate the organizational scope of the intervention as a research design variable to help leaders understand the level of resource commitment required for a given intervention. There is much yet to be learned about how these organizations, especially those with distributed functions (as is often the case with defense acquisition) learn, adapt, and share new knowledge. Perhaps the most interesting challenge is to understand ultimately how effective this form of organizational intervention can be as a bottom-up attempt to transform a complex system that has seen so many top-down change imperatives come and go.



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Many people and organizations have made significant commitments of time, energy, and resources to the success of Lean Now. Any list of participants would be incomplete and unrepresentative of actual contributions, and that list is growing with each passing event. Nevertheless, the efforts of Terry Bryan (Raytheon), Tracy Houpt (Lockheed Martin), Wes Switzer (Boeing), Rob Goetz (Northrop Grumman), and Thomas Winfield (Raytheon) deserve special recognition for the time, devotion, and professionalism exhibited in initiating and sustaining the Lean Now engagements mentioned in this article.



A PERSON-CENTERED APPROACH TO SUSTAINING A LEAN ENVIRONMENT— JOB DESIGN FOR SELF-EFFICACY

DAVID S. VEECH

Toyota credits its team members for the success and sustenance of the Toyota Production System. The power of a highly skilled and motivated workforce is a significant competitive advantage for any company, in any industry. Toyota's team members collectively make hundreds of thousands of improvements to their work every year, reducing costs, reducing cycle times, and improving working conditions. Drawing on old and new research, this paper poses a theoretical explanation for why employees get involved and stay involved in transformational activities in organizations. It will explore relationships between corporate belief systems, job and employee satisfaction, and individual self-efficacy and then offer a way for companies to apply all of these theoretical ideas through two practical tools.

Many organizations are attempting to implement Lean principles and practices through Kaizen events, Kaizen blitzes, accelerated improvement workshops, action workouts, or other-named activities that typically generate significant gains in productivity, inventory reduction, or other measurable parameters in a short time within the production system. In teaching and listening to leaders in most of these companies, I also hear about the difficulties they face in sustaining those gains. While I haven't collected any hard data yet, anecdotally these leaders estimate that the gains nearly disappear within six months of the event. As I explored with them the methods employed, it became apparent that they were unable to get

their operations-level employees fully involved to the point where they take ownership of the newly redesigned process.

In one recent discussion with a supervisor about the employees' attitudes toward Kaizen events, she told me (essentially) "We loved it the last time they [the Kaizen Team] came in. They helped a lot. We can't wait until they come back again." In a more rigorous study of the effects of Lean production on the workforce, Parker (2003) found that certain practices falling under the category of Lean production could be damaging to employees. She suggests "caution for companies considering Lean production initiatives, especially if they aspire to have a mentally healthy, self-efficacious and committed workforce" (Parker, 2003, p. 631). I believe her findings are valid, but I don't believe that her subject companies did anything Lean. I would expect the same kind of damage to employees in companies doing Kaizen events without modifying the systems supporting the value-adding operations, especially the system that measures and rewards the performance of leaders in the organization.

Typical Kaizen events focus all their energy on improving a particular process. In fact, we have been challenged to focus on process improvement for years, following the teachings of Deming (1986), Ohno (1988), Womack and others (1990, 1996.) While these esteemed researchers, leaders, and consultants also recognize the importance of treating team members with dignity and respect, their followers have apparently missed the subtlety of focusing on employee improvement instead of process improvement. If our focus is on improving people, a likely outcome is that those people will possess the right skill set to continue improvement activities on other processes. This is a fundamental shift in attitude for leaders. This further requires us to rethink our definition of success and how we evaluate managers.

What really makes the difference between a Lean organization and a conventional organization doing Lean things? Here's an excerpt from Toyota's Web site:

What Sets Us Apart?

The Toyota Production System is at the heart of everything we do. Based on the concept of continuous improvement, or Kaizen, every Toyota team member is empowered with the ability to improve their work environment. This includes everything from quality and safety to the environment and productivity. *Improvements and suggestions by team members are the cornerstone of Toyota's success.* (Emphasis added.) <http://www.toyota.com/about/operations/manufacturing/index.html>

It is obvious that Toyota links the role of its team members with the success of the Toyota Production System and therefore with the Toyota Motor Company. Team members who make small improvements every day, or who solve countless minor problems in the course of the shift, make the Lean system work on a sustainable basis. Companies may argue that Toyota has a unique environment, with high volume and highly standard products; therefore, Toyota's approach won't work for them. But since Toyota's approach is all about people, no one can argue that Lean thinking doesn't apply to their business—everyone has people.

What makes the difference between a Lean organization and a conventional organization is the way it treats its people. A true Lean organization focuses *first* on improving people, recognizing that a workforce with a higher skill set will accelerate any program of continuous process improvement. To help illustrate this point (Figure 1), let me briefly review my version of the Lean house (Veech, 2001).

In order to achieve customer satisfaction, a company must master Just-In-Time (JIT) and Jidoka in its value creating operations (whether manufacturing, service delivery, or supporting operations). Just-In-Time involves understanding work processes, and applying various Lean tools (5S, setup reduction, Kanban, work cells, etc.) to enable continuous flow through the work place. The JIT column is often called the "Go" column, because all the tools and techniques of JIT are designed to make the system go faster with less inventory required to support it. Jidoka refers to the interaction of the team members and the machinery. Under jidoka, we apply tools like andon systems to bring attention to problems, visual controls, operator inspection, and poka yoke, or mistake-proofing. This column is often called the *Stop* column because these tools are designed to stop the process to prevent any defects from proceeding.

In order to master JIT and jidoka, a company must build on a platform of employee satisfaction. (This is the area on which this paper focuses, so we'll get into much more detail later.) In order to create conditions satisfying to employees, companies must have stability at the foundation of its system. The significant elements of stability and employee satisfaction are all human issues and apply universally to any business. Let's take a closer look at these two pieces of the house.

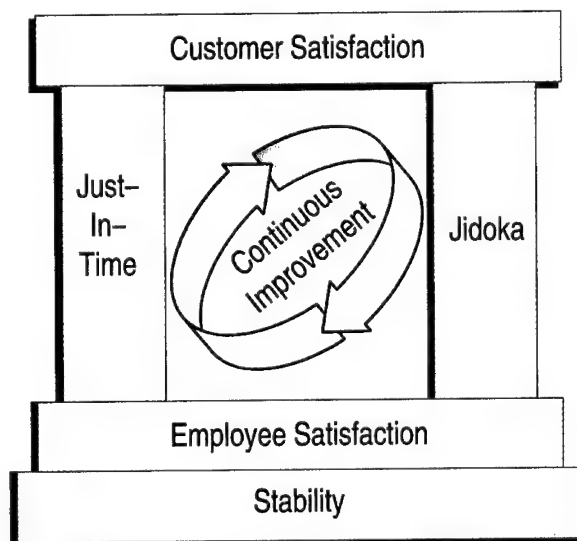


FIGURE 1. THE LEAN HOUSE

STABILITY

A Lean company recognizes that stability doesn't equal rigidity. Stability simply refers to the framework within which the company performs its work. Stability means people and processes are operating steadily, as needed, with predictable outcomes. The word "operating" makes this dynamic rather than static. The phrase *as needed* is important in this definition because we don't seek a system that is always on, unless the demand on that system requires it. We want a system that will work when we need it, stop when we don't, but start back up immediately at the demand of the customer (Veech, 2001). There are four elements of stability that organizations must put in place and maintain:

1. **Trust** between management and the workforce, between the different departments within the company, and between members on teams;
2. **Commitment** from visionary leaders throughout the company, manifested in servant leadership and loyalty, and from the employees, manifested in organizational citizenship behaviors, including the discipline required to adhere to standardized work practices;
3. **Situational awareness**, or possessing a complete understanding of what's going on in the work/business environment, including having processes that are understood and statistically under control; and a
4. **Trained and empowered workforce**, understanding that it is the leader's responsibility to equip the workforce to accomplish the tasks for which she wishes to empower them.

EMPLOYEE SATISFACTION

A Lean company seeks to provide a work environment that satisfies and motivates its team members. We want team members to identify problems and to generate effective solutions. Satisfied employees are more likely to take that step. To get there, leaders need to understand a little more about people in the work place. Motivation and satisfaction have been topics of study for years with various ideas submitted, but the bottom line is that each of us is motivated by something different. The task of the leaders in a Lean environment is to know their team members well enough to be able to identify what that is, and then find a way to offer it as an incentive.

One of the most powerful motivators is simply a team member's own assessment of his or her ability to do the work we're asking them to do. This is individual self-efficacy. If a team member is confident in his or her ability to perform a particular task, he or she is said to have high self-efficacy toward that task. Those with high self-efficacy are the ones most likely to muster the motivation to attempt the work and then to try and improve the work. They are also more willing to try new things.

Leaders can take action to create an environment that enhances the self-efficacy of the workforce.

"One of the most powerful motivators is simply a team member's own assessment of his or her ability to do the work we're asking them to do."

Creating a satisfying work environment will have an enhancing affect on self-efficacy. Certain studies identify meaningfulness, awareness, and responsibility as a set of critical psychological states that contribute to job satisfaction.

- Meaningfulness derives from task identity, task significance, and skill variety (Hackman & Oldham, 1976). We can create meaningfulness in the operations area through job classifications and standardized work, which allows the team member to identify with the tasks at hand; communicating the value each team member adds at each work area; and rotating work arrangements, providing opportunities for learning new skills.
- Awareness is brought about partially through feedback, which provides knowledge of results for the team member. Awareness also includes a full understanding of the requirements of the job, both at the workstation itself, and within the entire system. Leaders can provide feedback directly, or they can create systems that allow the team members to know the status of the work (and their performance) at any time.
- Responsibility requires that we equip our workforce for the tasks at hand, and then turn them loose to do them. This autonomy reflects to the empowerment mentioned earlier as an element of stability. It also includes the degree to which the employee has control over his or her own work environment.

SELF-EFFICACY

Apart from providing a satisfying work environment, there are four other primary contributors to self-efficacy (Stajkovic & Luthans, 1998): (1) Mastery of the skill or task; (2) verbal persuasion, manifested in coaching and teaching; (3) learning, through observing the behaviors and consequences of others; and (4) motivation.

Mastery implies a significant skill level and thorough understanding of the work. Team members attain mastery through an ongoing series of enactive experiences. Stajkovic and Luthans (1998) define *enactive mastery* as *succeeding in a challenging task*. But mastery is virtually unattainable without the interactions of the other three elements identified above.

To reach a level of mastery requires a coach who, in a Lean environment, is the first line leader. Both the first line leader and a team member's teammates provide the opportunity to learn by observing others (a powerful and effective human learning tool). But without some degree of motivation, those lessons won't show up in the changed behavior we seek.

***"Motivation leads to higher self-efficacy,
which leads to achievement and mastery,
which leads to more motivation for
more difficult or challenging tasks."***

Motivation by itself comes in as many forms as there are people, but generally the things that motivate team members include achievement of the job itself, responsibility, advancement opportunities, rewards of some form or another, or recognition for the accomplishment (Herzberg, 1987). Motivation leads to higher self-efficacy, which leads to achievement and mastery, which leads to more motivation for more difficult or challenging tasks.

Meaningfulness and awareness are also inputs to mastery, allowing us to link satisfaction and self-efficacy. Those who derive meaning from their work are likely in principle to continue to accept challenging tasks. Awareness wrought by feedback from leaders with respect to a team member's performance not only contributes to satisfaction but is also a direct contributor to self-efficacy (Bandura & Locke, 2003). Bandura and Locke (2003) go on to conclude that even bogus information is used by individuals to make their judgments of self-efficacy, citing a study where individuals were lead to believe they were in a higher or lower percentile rank in (this case) pain tolerance. Those lead to believe they were in the higher percentile gained more tolerance for pain in subsequent experiments.

This may transfer as well to a workplace where leaders could provide performance feedback in a particularly positive light, without falsifying data, in an effort to boost performance in a subsequent activity. In other words, if we tell a team completing a Kaizen event that their results are comparatively high with respect to key measurements, then we could expect this team's efficacy toward subsequent events to be higher. The opposite should be true as well. If a team has a particularly bad experience with

a Kaizen event, they may not want to do another. I believe this is why Parker (2003) drew her conclusions associating Lean practices with lower self-efficacy.

"We want to design jobs with satisfaction and self-efficacy in mind, understanding that to get satisfaction, we as leaders need to provide for meaningfulness, awareness, and responsibility."

What a Lean organization seeks is a level of self-efficacy that encourages team members to automatically engage in problem solving and continuous improvement in the operations area. We need *enhanced* self-efficacy and systems to encourage team members to generate, test, and implement ideas for improving processes or methods in real time, while they are working. Responsibility, as an element of satisfaction, should also be relevant here.

True autonomy gives control of the work environment (responsibility for the performance of the system) to the individual team members. (See Toyota's quote again!) Providing team members with control over his or her work environment further enhances self-efficacy (Bandura, 1991; Wood & Bandura, 1989). Bandura and Locke (2003) cite studies from the 70's and 80's that lead them to conclude that people who believe they are in control of aversive events around them suffer less performance impairment than those who do not.

SYNTHESIS

If we now refer to Figure 2, we can summarize the requirements of a sustainable Lean system. We want to design jobs with satisfaction and self-efficacy in mind, understanding that to get satisfaction, we as leaders need to provide for meaningfulness, awareness, and responsibility. As we perform these newly designed jobs within a team environment, providing positive coaching instead of directive supervision, these satisfying jobs will lead to enhanced self-efficacy and higher motivation. From this state, we expect team members to take a greater interest in the work they do, resulting in persistence on the job and ideas for improvements, even in the face of resistance or obstacles. We expect the coupling of ideas and motivation to drive our team members to take initiative in the workplace, which will show up in suggestions for improvements and in direct improvements to our standardized work, reinforcing the team member's control of the environment and further enhancing self-efficacy. This is a self-generating system from this point on.

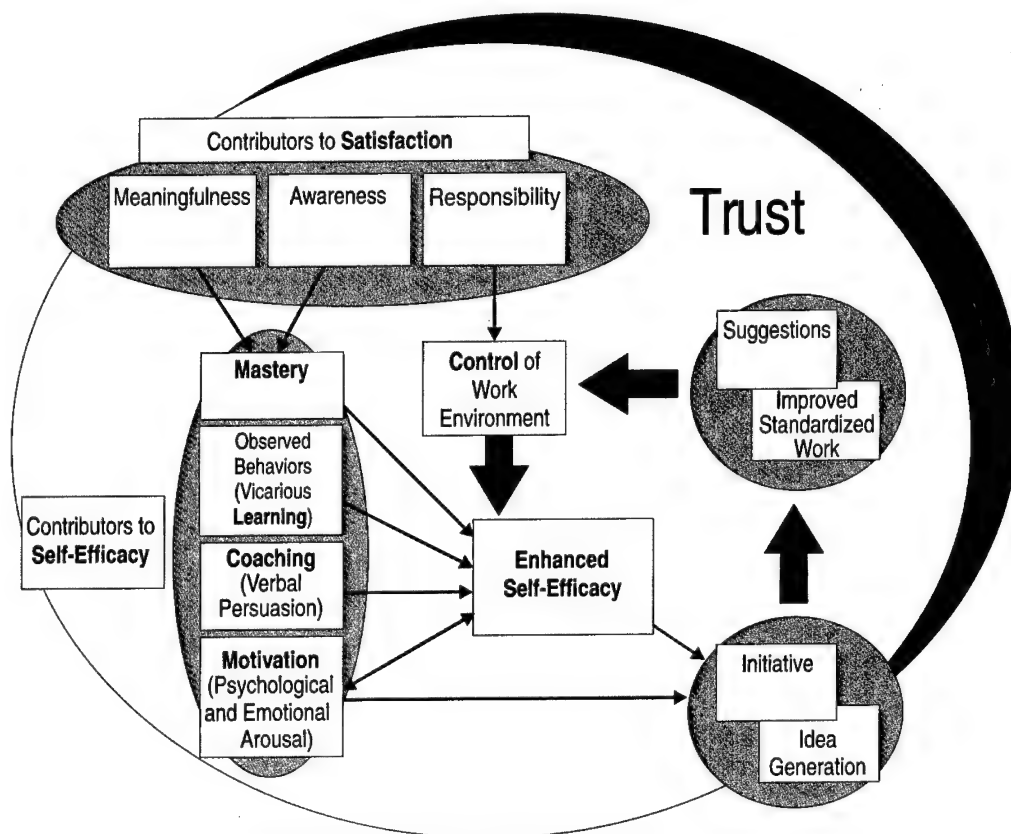


FIGURE 2. JOB DESIGN FOR SELF-EFFICIACY

The only remaining label on Figure 2 is *Trust*. Without trust between labor and management, between team members on teams, and between different functional divisions in the organization, none of this will work for long. Leaders must be honest and trustworthy at all times. But there is a brutal honesty that should be softened in respect to the team members, much the same as we tell our spouses that the ugly shoes they love the most look wonderful on them.

Building trust takes us right back to a focus on improving people and treating them with dignity and respect. Of all the tools available to companies wanting to become Lean organizations, I believe the two that will help them most in getting sustainable results are standardized work and suggestion systems.

STANDARDIZED WORK

Both the development and the enforcement of standardized work provide the opportunity to build trust in organizations. In a conventional organization, managers

or engineers typically design a particular job, prepare detailed work instructions, and send the instructions to the workplace expecting those instructions to work when applied. Many times, the manager or engineer is unfamiliar with the actual operations in the workplace, so the instructions seldom work without modification. Often, the modifications go unrecorded.

In a Lean organization, well-coached team members prepare the standardized work to reflect exactly what they do. Involving the workers and providing for their self-determination increases their level of trust of supervisors (Deci, Connell, & Ryan, 1987 in O'Reilly, 1991). In preparing the standardized work documentation, the team members, supported by leaders and supporting engineers or specialists, verify the best way to do a particular job and take the time to precisely record every activity required. This documentation becomes the basis for performance, or provides the daily performance expectations. Team members know immediately what they have to do, and how well they have to do it.

"Both the development and the enforcement of standardized work provide the opportunity to build trust in organizations."

In a continuous improvement environment, we require the team members to have the discipline to follow the standardized procedures without variance. Enforcing the standardized work by ensuring that the job is performed the same way every time is important for a number of reasons.

First, repetitious performance builds self-efficacy in the team member. The team member learns how to do the job better each time he or she performs, developing mastery of the process. Appropriate modeling by lower-level leaders enhances the learning experience and the level of trust between the team member and the leader (Stajkovic & Luthans, 1998). Positive results further reinforce the learning, encouraging the team member to repeat the desired behavior (Bandura, 1991; Gist & Mitchell, 1992).

Second, repetitious performance by either the primary operator or any other operator who steps in for him or her is likely to reveal problems in the design of the work. Steps that add time or unnecessary movement of the team member or his materials will become evident as each other team member attempts to achieve the standard identified in the standardized work. This, in addition to providing meaningfulness, is another benefit of job rotation.

The greatest value in standardized work, however, is in the freedom of the operators to solve problems, to find a better way to do the job, to test that better way, and then to implement the better way as the new standard. While there must be specific procedures to follow in changing the standardized work, the focus of control for the

operators is high, enhancing their efficacy and likelihood of success on the job (Wood & Bandura, 1989; Bandura, 1991). By not only allowing but also teaching and encouraging the team members to improve their processes, leaders further enhance their trustworthiness.

"The greatest value in standardized work, however, is in the freedom of the operators to solve problems, to find a better way to do the job, to test that better way, and then to implement the better way as the new standard."

Finally, by consistently enforcing the standard, leaders may reduce the perceptions of procedural injustice in the workplace.

SUGGESTION SYSTEMS

Another trust building tool for our stable organization is a suggestion system. Many organizations have provided suggestion programs for their employees with varying degrees of success. In a Lean organization, the primary objective of the suggestion system is not to solicit the participation of our team members by extracting their good ideas, but to provide a consistent vehicle for teaching individual problem solving skills. The suggestion system is a *training tool* for individual problem solving. To make this suggestion system work, leaders must commit to helping the team members complete a defined problem-solving process for every idea or suggestion they have. Leaders have to provide access to all the information a particular team member may need to support his or her suggestion. This might include access to engineering, or to finance and accounting to quantify the magnitude of the problem and the solution. Leaders commit to responding within 24 hours to every suggestion submitted and to approving the suggestions at the lowest level possible. The supervisor of the person with the suggestion should have the authority to approve the vast majority of suggestions after helping the team member complete the problem solving process and document the findings on the suggestion form. If we stay focused only on improving the process, we lose sight of the true value of the suggestion system—improving the people.

CONCLUSION

So, does focusing on improving people mean we don't measure productivity, cycle times, or costs? Absolutely not. Does focusing on improving people mean we stop doing Kaizen events, accelerated improvement workshops, Lean events, or action workouts (choose your favorite label)? Absolutely not. Focusing on people doesn't relieve us from the burden of getting results, so we will continue to set goals based on various measures.

What needs to be different, though, is how we view Kaizen events, suggestion systems, and job design. In a conventional organization, these three activities focus on getting things from the employee (improved productivity, ideas, work) rather than providing something to the employees. If we were to view them instead as tools for improving people, these become learning activities and provide skills and opportunities to employees. Results are still important. But even more important is developing in the workforce the skills needed to sustain improvements. Focus on the people and the results will follow. Focus on the results, and you'll have the same troubles as everyone else—poor follow-up, lack of interest, no ownership of improvements, diminishing productivity. What really needs to be different is attitude.



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Joint Strike Fighter

Courtesy of Lockheed Martin Corporation

THE LEAN ENTERPRISE— A MANAGEMENT PHILOSOPHY AT LOCKHEED MARTIN

MICHAEL JOYCE AND BETTINA SCHECHTER

In 1999, Lockheed Martin developed an approach called LM21, for Lockheed Martin in the 21st century, to identify best practices for increasing efficiency and improving financial and operating performance. Leaders soon realized that best practice sharing was just one means to a higher end. The ultimate goal is to create a system that consistently achieves excellence for our customers, shareholders, and employees. We selected and implemented the management philosophies called Lean and Six Sigma. This article describes the Lean Enterprise at Lockheed Martin and the steps taken to make it a reality.

Lockheed Martin is the world's largest defense contractor, a company built by a strategic vision of merger and acquisition that characterized the mid- to late-1990s. Rooted in the heritage of 18 different companies, Lockheed Martin set out in 1999 to identify and share best practices to increase efficiency and improve financial and operating performance. While this approach, called LM21 for Lockheed Martin in the 21st century, did identify many best practices, leaders and employees alike soon began questioning the real end objective of the exercise. The realization is that best practice sharing is just one means to a higher end. The ultimate goal is to create a system of work, or operating system, that consistently achieves excellence for our customers, shareholders, and employees.

In early 2000, the title of the effort was changed from LM21 Best Practices to LM21 Operating Excellence. We then looked at the challenge of defining and achieving Operating Excellence and found that, in addition to transferring good ideas, we needed a consistent set of principles and behaviors that would drive

us to continuously improve and continuously learn. When we looked both internally and externally for a set of proven concepts, we selected the management philosophies called Lean and Six Sigma. Many of the Lockheed Martin businesses were familiar with Lean and/or Six Sigma and had been using these tools to eliminate waste and variation in their isolated processes. LM21 quickly became the common corporate drive for application of the Lean and Six Sigma philosophy and methodology throughout the Lockheed Martin enterprise, with coordinated efforts in training and standard application of the tools.

Almost four years later, LM21 has become a workplace standard and a mindset. The Lean/Six Sigma principles of process improvement have migrated to every business function: Finance, Business Development, Procurement, Operations, Human Resources, Cash Management, Contracting, and Engineering, to name a few.

"The Lean/Six Sigma principles of process improvement have migrated to every business function: Finance, Business Development, Procurement, Operations, Human Resources, Cash Management, Contracting, and Engineering, to name a few."

More than anything, LM21, the pursuit of Operating Excellence, is a management mandate with active participation of every employee. Leading this charge to Excellence are the corporation's top managers. More than 8,000 of them—ranging in level from the chief executive officer to corporate executive and program managers—have participated in a 4-1/2 day Lean Leadership training program. The program requires leaders to complete a real-time transfer of learning into action by conducting an improvement event in their business area. These actions, coupled with the work of more than 6,000 employees trained as experts in the principles of Lean/Six Sigma, have generated thousands of improvements that have touched virtually every one of our 125,000 employees. Significant in this approach is the engagement of our customers who are also trained and participate in improvement activities with us. It is most evident that Lockheed Martin has transformed its operating system in continual pursuit of a Lean Enterprise.

In the remainder of this article we will describe the Lean Enterprise at Lockheed Martin Corporation and the approach we have taken to make this a reality in our business. We believe the reader can use the methodology and path we have taken to drive Operating Excellence in their own domain.

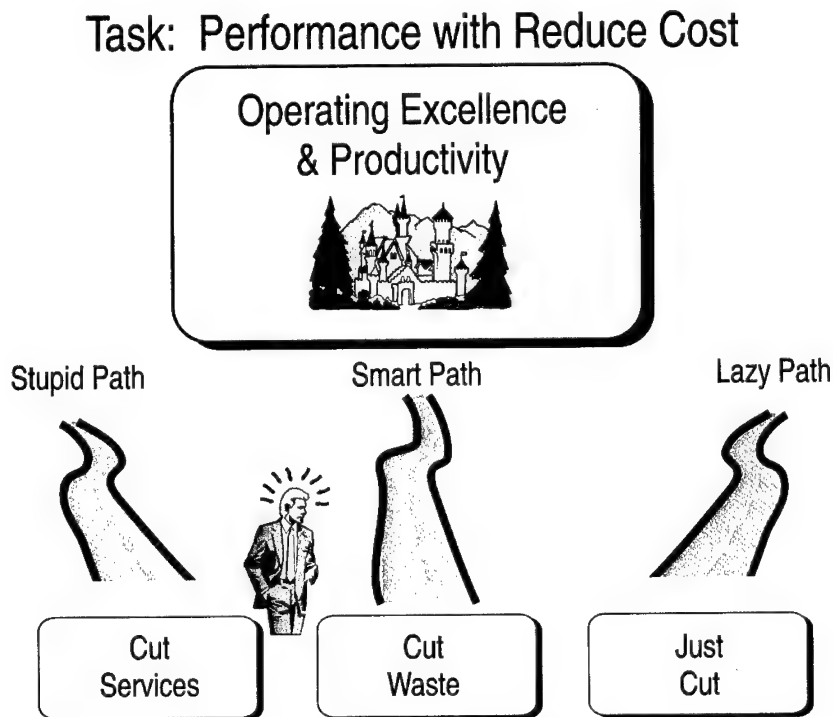
LEAN ENTERPRISE—A MANTRA OF CONTINUOUS IMPROVEMENT

At the core of the Lean Enterprise is a philosophy of continuous improvement of the work that we do. Regardless of the task—compile data for management reports, assemble a wiring harness, or schedule air combat training—“make it better” is the mantra.

We drive this engine by insisting on a year over year reduction in cost in every program and department. Faced with this challenge, leaders can choose from a short list of scenarios. (See Figure 1.)

Scenario One: Cut budgets. How many times does management edict an across-the-board percent-reduction in budgets? Shave 10 percent or 20 percent. Just cut. Lazy managers do this by taking the easiest path of asking everyone equally to cut back. It is a lazy approach because it requires little skills or knowledge of the work; unfortunately, it also leads to unintended consequences as cut to value added work would result in poor program performance. This is the lazy path.

Scenario Two: Cut service. How often are costs trimmed by eliminating a particular service or feature? Certainly an immediate reduction arises. But what if the curtailed service is something the customer wants and is willing to pay for? What if the service is something your competitors can also supply? So the



LM21: Lean Processes that Operate at Six Sigma Capability

FIGURE 1. COST REDUCTION SCENARIOS

unintended consequence is a loss of or dissatisfaction by your customer base. This is the stupid path to change.

Scenario Three: Cut waste. The path of Operating Excellence and the key to a Lean Enterprise is attacking waste. When given the goal to take cost out, managers need to carefully examine an entire value chain to identify wasted activity and sources of variation and then work with their entire organization to eliminate them. This is the smart path.

So, how do you cut cost smartly and provide an environment of continuous improvement? Lockheed Martin's answer is a unique blending of Lean Thinking and Six Sigma methodology. The resulting formula, called LM21, has made a tremendous impact to the Corporation.

"The path of Operating Excellence and the key to a Lean Enterprise is attacking waste."

LM21 is the *how to* guide for cutting cost and improving quality and customer satisfaction. It builds on the five principles of Lean as a set of leadership and decision making mandates that define excellence:

1. Customer Value – define it from the customer's perspective.
2. Value Stream – identify all activities used to make a product or provide a service.
3. Flow – create a system where value is continuously added. Clear away obstacles that don't add value or clog the value stream.
4. Pull – initiate work only at the demand and to the specific specifications of the customer.
5. Perfection – continuously refine the process to improve efficiency, cycle time, costs and quality.

Principles of Six Sigma—which embody the fifth principle of Lean, *Perfection*—complement this methodology, honing processes to make them more reliable, repeatable, and predictable. Six Sigma is a data driven methodology that focuses on driving to perfection all business, technical, and operational processes and results—encompassing defect prevention, eliminating variability and mistake proofing through the use of data driven tools. The merging of these two methodologies provides a powerful and proven approach that engages the entire workforce in continuous improvement.

This is the philosophy and toolset driving Operating Excellence at Lockheed Martin.

INFRASTRUCTURE: A FOUNDATION FOR THE LEAN ENTERPRISE

To institutionalize LM21, Lockheed Martin has developed an infrastructure and management strategy and approach to introduce principles; demonstrate a clear need to continuously improve; set management expectations for improvement; provide the tools, talent, and other resources necessary; and ensure follow-up and that the savings opportunities are realized. This infrastructure links **Leadership** with a **Strategic** focus to a **Tactical** deployment—with all three needing to be present and working together in a closed-loop environment (where there is continuous feedback of expectations and results) to be effective. (See Figure 2.)

A question to be answered in promoting a Lean Enterprise is how and where do you get started? Early in the LM21 maturity path, emphasis was placed on training and holding events (events are activities in varying duration of length that engage the experts and people who do the work, to change their process based on the principles of Operating Excellence) to get as many employees and leaders as possible to experience the Lean and Six Sigma tools (e.g., process mapping, statistical analysis, time analysis, defect analysis). This reinforces the belief that *to see is good, to do is better*. Once people have experienced success with the tools, they become believers and they are champions for change. Selection of processes and opportunities to attack, however, were often tactically driven, and while results were achieved (in terms of dollars saved or cycle time reduced), there was little integration of efforts with each other or with the business's strategic plan.

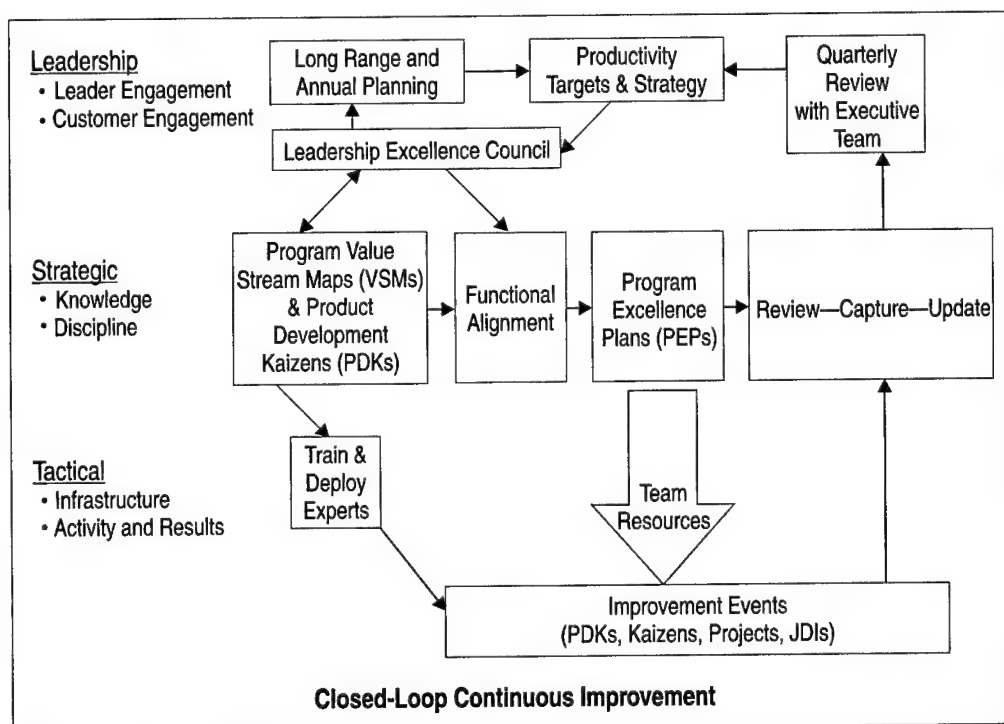


FIGURE 2. LM21 OPERATING EXCELLENCE DEPLOYMENT

As the capability of the Corporation grew to hold productive events and sustain results, the LM21 toolset grew with the addition of the **Value Stream Map (VMS)**. This tool gives leadership a strategic look at its value streams (Lean principle number two) and the ability to see waste in the operating system at a macro level. As part of the process, leaders identify and prioritize the improvement events necessary to eliminate the waste, such as Kaizen events (an activity where a team is chartered for a period of 3–5 days, to identify waste for a given process and implement immediate, sustainable solutions for waste elimination/reduction), other VSMs, projects (an activity that can occur over several months focusing on a process improvement requiring extensive work and change) and **Just Do Its** (short term projects that require few resources and limited amounts of time and resources to complete). The result: a plan is in place to strategically identify and eliminate the waste that most interferes with the ability to deliver value to the customer. (See Figure 3.)

As VSMs became widely used across Lockheed Martin and events were more clearly linked to operating plans and business objectives, each business set up another important facet of its infrastructure—**Leadership Excellence Councils**. Comprised of senior leaders within each business, these councils meet regularly to discuss LM21 progress and determine where resources should be allocated to have the biggest impact in the business. The councils also assign the talent (in this case, Green Belts and Black Belts) to lead and facilitate successful events and commit resource allocation when new opportunities are uncovered.

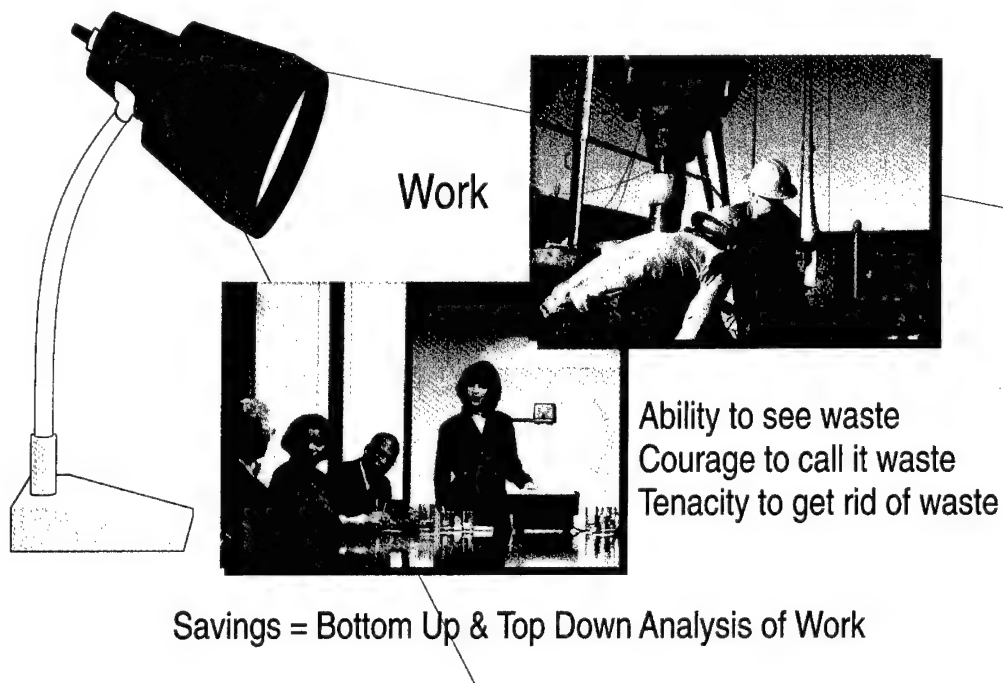


FIGURE 3. LEAN PROCESSES WITH SIX SIGMA CAPABILITY

Within Lockheed Martin, the great majority of our customer value comes via a customer program and program office. Therefore, the key ingredient in the strategic application of this process and resource is the **Program Excellence Plan**. The plan looks strategically at the program, its value stream, and its performance compared to what the principles of excellence demands and identifies gaps and plan improvement activities.

While much of this effort is aimed at programs that are already engaged in producing products and services, Lockheed Martin sees tremendous opportunity to work on the front end of the product lifecycle, in the proposal and design phases. LM21 has created a tool called Product Development Kaizen (PDK) for this critically important part of the program. PDK is a generic term for three related tools: Pre-Proposal Kaizen, Pre-Design Kaizen, and Pre-Production Kaizen, which help define the enablers needed to deliver a product or service in the time, cost, and performance the customer wants. These tools, as their names suggest, are applied at different stages of the development process of a product or service.

***"PDK is a generic term for three related tools:
Pre-Proposal Kaizen, Pre-Design Kaizen, and
Pre-Production Kaizen, which help define the
enablers needed to deliver a product
or service in the time, cost, and
performance the customer wants."***

The new objective achieved in using this tool is to apply the same system engineering disciplines we use on our products to design the systems of work we will deploy on new programs. These tools have had a tremendous impact on Lockheed Martin's success in winning new business with competitive pricing and improved profit margins.

Lockheed Martin emphasizes the continuous nature of LM21 improvement by setting annual savings targets that equate to a percentage of sales. Each year, Lockheed Martin businesses are required to look for ways to improve their processes by eliminating additional waste. This pursuit of Excellence will never end, and looking for and eliminating waste becomes a way of doing business—a management philosophy.

Lockheed Martin has also worked closely with hundreds of suppliers in the pursuit of Excellence by engaging them in events, training, and planning that improves the entire supply chain. As much as 60 percent of program costs can come from the supply chain. The company has taken strategic looks at its supply chains and identifies key suppliers that have a track record of success and provide valuable services. Lockheed Martin then partners with them to identify opportunity to eliminate waste so that cycle times and costs can be reduced.

PEOPLE ENGAGEMENT

Central to the LM21 approach is measuring reality; and who better to know it than those closest to the products and services. Lockheed Martin is about people—from corporate executives to front-line workers. Embracing the philosophy of Just Do It is one of the ways people are engaged in LM21 and the pursuit of Excellence.

The concept of *Kaizen Management* is a major element in which leadership provides direction and then allows those who do the work to change their process in a formal event. All employees have accountability to act and behave following the five principles of LM21. In this model, leaders stay engaged and connected throughout, and front-line workers are encouraged and supported to make changes to continually improve their work environment.

"The concept of 'Kaizen Management' is a major element in which leadership provides direction and then allows those who do the work to change their process in a formal event."

In this way, Lockheed Martin's strategy is characterized by a top down and bottoms up approach, which reinforces that LM21, at its core, is a management philosophy. A knowledgeable and engaged leadership sets improvement strategies linked to business goals, sets targets and objectives, and provides resources. Managers and employees use the LM21 tools with the help of trained experts to improve their work areas. All 125,000 Lockheed Martin employee, managers and leaders are marching in the same direction, in pursuit of Excellence.

ACHIEVING OPERATING EXCELLENCE

While definitions for Operating Excellence are plentiful, a common thread is delivering on customer expectations—providing results. LM21 has helped Lockheed Martin excel in this capacity. Not only has the company saved itself and its customers billions of dollars, but LM21 actually helps improve customer relationships. This has been measured in improved customer ratings and satisfaction with current programs and services, the capture of repeat business, and the winning of new business. We have seen this work in major acquisitions, such as the Joint Strike Fighter (JSF) or F-35 Fighter, where customer timing and acquisition costs required new ways of doing business. By continually applying these concepts, even when our customer is highly satisfied, we have seen tremendous opportunities open. The

first principle of LM21 mandates understanding value from the customer's perspective—to do this, you have to know your customers and their needs. Our company slogan, "At Lockheed Martin, we never forget who we work for," reflects this passion for customers.

And, in today's world, customer needs change rapidly. Lockheed Martin uses LM21 to develop an operating system that has the *discipline* to deliver results reliably and the *flexibility* to change and grow in step with the customer.

Operating Excellence at Lockheed Martin is not an option; it is a business imperative. Customers expect it in the products and services they receive. Shareholders expect it in their investments. Employees expect it in their on-the-job challenges and workplace environment. LM21 enables the success of Operations Excellence and requires all Lockheed Martin people to be fully engaged and connected.



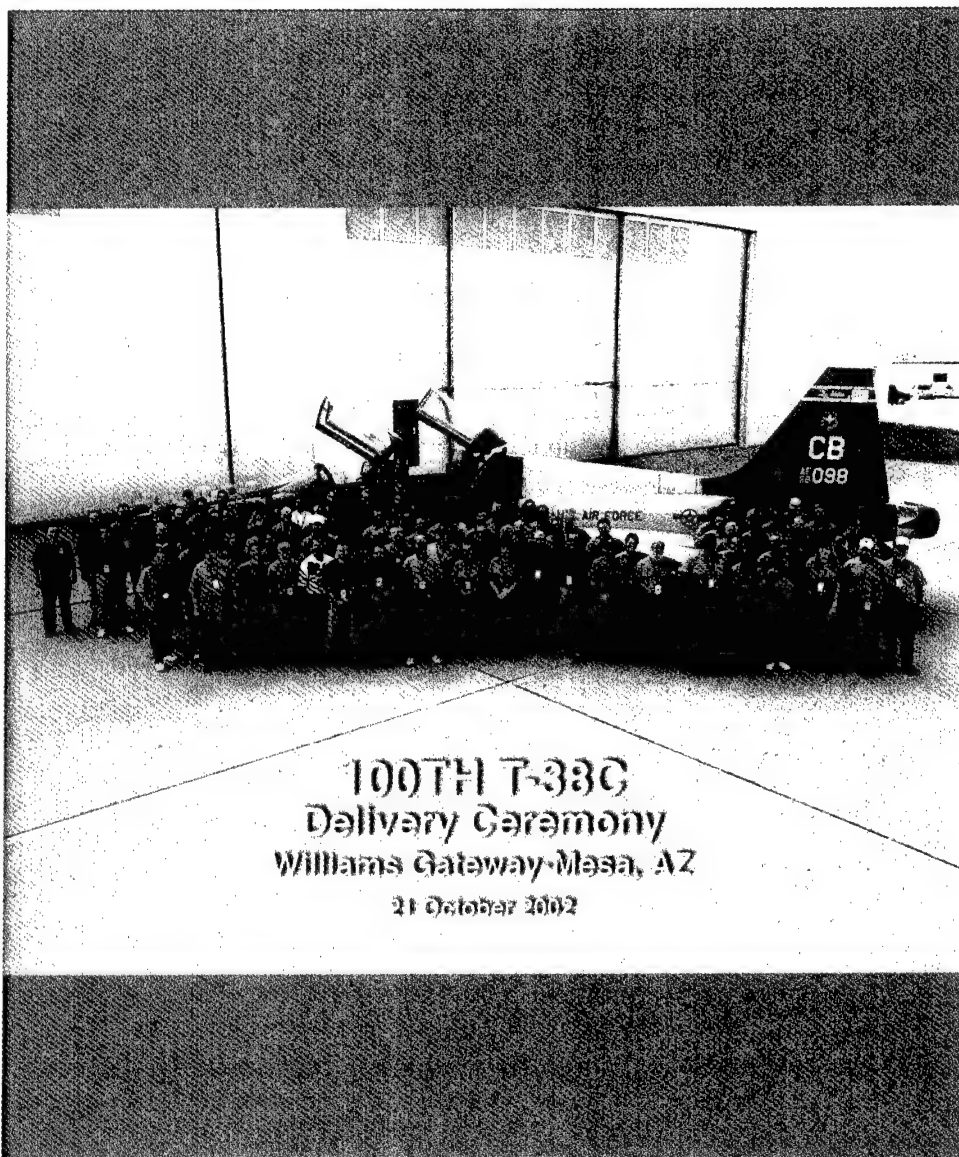
Michael Joyce is Vice President of Lockheed Martin in the 21st century (LM21) Operating Excellence. He was formerly the Vice President of Operations for the Aeronautical Systems Business Unit responsible for overall operations and supply chain management across the business unit. He joined Lockheed Martin in August 1997. Joyce has over 25 years experience in a broad variety of aerospace systems. He holds bachelor's degrees in mechanical engineering and mathematics from Columbia University in New York City and a master's degree in mechanical engineering from Rensselaer Polytechnic Institute in Troy, New York.

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T-38C TRANSITION TO LEAN

DAVID D. OTT AND JAMES B. DAVIS

In 2000, the United States Air Force T-38 Avionics Upgrade System Program Office began to pursue Lean initiatives to reduce out-year program cost and delivery risk at the Boeing T-38C Upgrade facility located at Williams Gateway Airport facility in Mesa, Arizona. The T-38 Avionics Upgrade Program production system baseline plan was conventional for legacy aircraft upgrade and modification programs using a mass/craft assembly stationary dock approach. For a successful transition from conventional to Lean production, program management support is critical. The T-38 Program Office in St. Louis, Missouri proposed a four-phase approach to implementation. This approach and the benefits derived from the process are discussed.

The United States Air Force T-38 Avionics Upgrade System Program Office (SPO) expressed a desire in the fourth quarter of CY2000 to pursue lean and efficient initiatives to reduce out-year program cost and delivery risk at the Boeing T-38C Upgrade facility located at Williams Gateway Airport facility in Mesa, Arizona.

Although lean or cellular manufacturing principles can be found in aerospace production facilities across the industry, most activity has centered on new build part fabrication or new build airframe assembly. Legacy aircraft upgrades, modification, maintenance, and overhaul activities have been slower to embrace the Lean culture. Literature suggests that reluctance is due in part to the variability in work content and scope that intuitively would disrupt production system efficiencies based on standardized repeatable work.

The T-38 Avionics Upgrade Program (AUP) production system baseline plan was conventional for legacy aircraft upgrade and modification programs using a mass/craft assembly stationary dock approach. Figure 1 pictorially represents the facility layout with the inherent stationary dock characteristics of people, parts, processes, and test equipment moving to and from aircraft with little resemblance of continuous or straight-line flow.

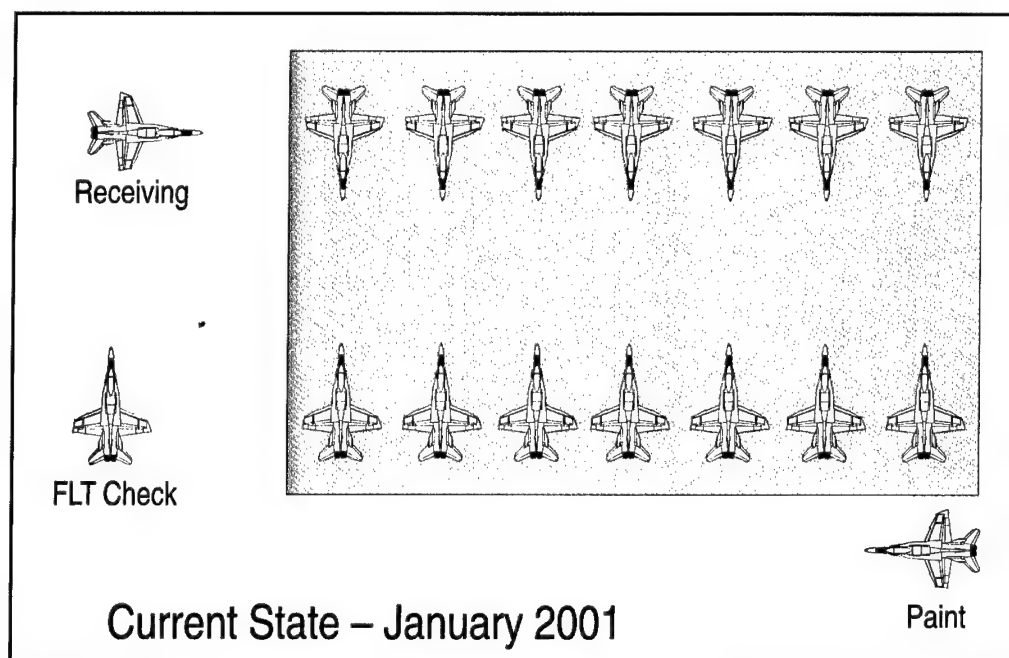


FIGURE 1. MASS/CRAFT ASSEMBLY PRODUCTION SYSTEM

Coincident with a desire to implement Lean principles at the T-38 Avionics Upgrade Production Facility, the upgrade production rate was scheduled to increase from 2 to 7 aircraft per month beginning January 2001 through March 2002.

THE PLAN

The T-38 Program Office in St. Louis, Missouri, responded to the customer's request by providing a statement of work (SOW) based on the systematic deployment of Lean Production Tactics. Figure 2 documents Lean Production Tactics and the evidence, in a context of tangible deliverables, that tactics have been deployed.

The SOW proposed a four-phase approach to Lean implementation.

- | | |
|-----------|---------------------------------|
| Phase I | Mobilize the Commitment to Lean |
| Phase II | Transition Planning |
| Phase III | Implementation |
| Phase IV | Sustaining the Gain |

The SPO funded Phase I of the Boeing proposed SOW in the form of a manufacturing study contract signed on April 18, 2001. The study was intended to determine the applicability and benefits of Lean principles in the T-38 avionics upgrade environment and recommend a go-forward position and strategy.

The motivation for both Boeing and the Air Force to study and implement Lean was bottom line financial performance. Boeing would benefit from aggressively

Production Tactics		Deliverable
1	Value Stream Analysis	Current and Future State Maps
2	Balance the Line	All Work Distributed by Shift and Position
3	Standardize Work	Operator Sequence Charts/Bar Charts in Place
4	Visuals in Place	Operator Sequence Charts/Bar Charts Colored to Visually Display Scheduled and Actual Work Status/Quality Metrics/Cost Metrics
5	Point of Use Staging	Jobs Kitted and Staged at Point of Use and Refill Process in Place
6	Feeder Lines	Parallel Worked Moved to Feeder Lines
7	Continuous Flow Line	Product Flow is Pulsed Using an Andon System/Product Moving at TAKT Time

FIGURE 2. LEAN PRODUCTION TACTICS

implementing Lean principles thereby converting cost to earnings for the remaining contracted fixed price options. The Air Force would benefit through substantiated out-year cost base reductions for approximately 50 percent of the production quantities not yet contracted.

Figure 3 presents the proposed SOW Phase sequences and spans. The proposed phase span times were representative of successful activities pursued on similar Boeing Integrated Defense Systems programs and were used to support initial resource and cost estimating.

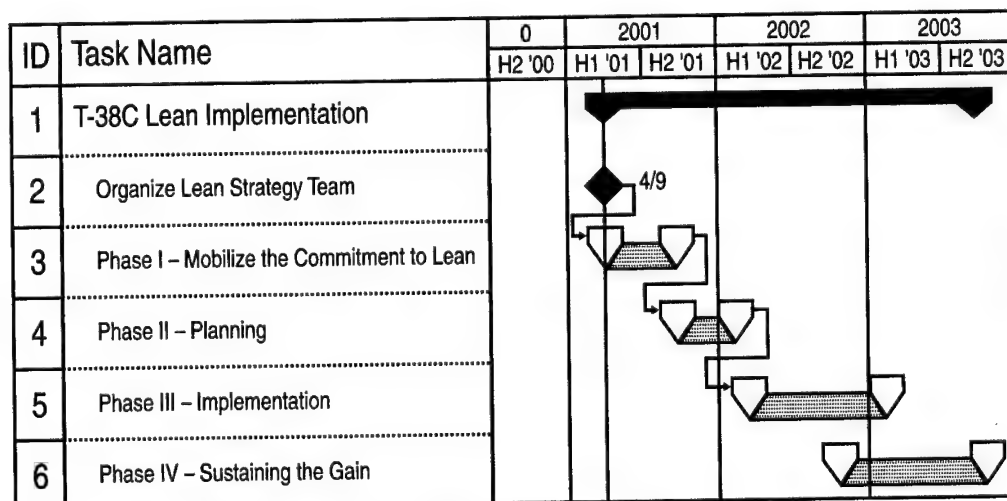


FIGURE 3. STATEMENT OF WORK PHASE SEQUENCES

Funding for Phases II, III, and IV implementation were dependent upon compelling business case substantiation based on the future state value stream performance.

THE APPROACH

Program management support is the critical element of a successful transition from conventional to Lean production. Support materializes in the form of training budgets, a willingness to challenge legacy systems and processes, and a consistent resolve to stay the course for change amid inevitable cultural pushback and challenges. The T-38 AUP was fortunate to have visionary managers within Boeing and the System Program Offices. The objective of Phase I—Mobilize the Commitment to Lean—was to identify potential performance benefits and non-recurring expenditures required to transition the T-38C program to a Lean enterprise.

Lean manufacturing specialists were assigned to the T-38C program in May 2001 in order to begin Phase I activities. St. Louis and Mesa T-38C program personnel, suppliers, and SPO representatives were trained on Lean principles, value stream mapping, and value stream analyses for the purpose of defining the current state product and information flows. The format of training consisted of lectures followed by hands-on simulations reinforcing Lean principles.

A weeklong Production Preparation Process (3P) event lead by Boeing certified Lean practitioners was held at the Williams Gateway Facility in July 2001. The 3P deliverable was a Lean future state value stream upon which a benefit comparison analysis to the current state was performed. Participants included production personnel (60 percent), production support and process owners (30 percent), and management (10 percent). Figure 4 highlights 3P events critical to creating a realistic future state production system.

The three fundamental tenants for the future state T-38 Avionics Upgrade Program Production System were TAKT-timed production paced to meet customer's rate of demand, one-piece flow, and pull production. (In a world of acronyms, TAKT is not one of them. TAKT is a German word loosely translated to a conductor's baton or more closely associated with a drumbeat. TAKT-time is a technique used to coordinate and synchronize certain activities.)



FIGURE 4. PRODUCTION PREPARATION PROCESS EVENTS

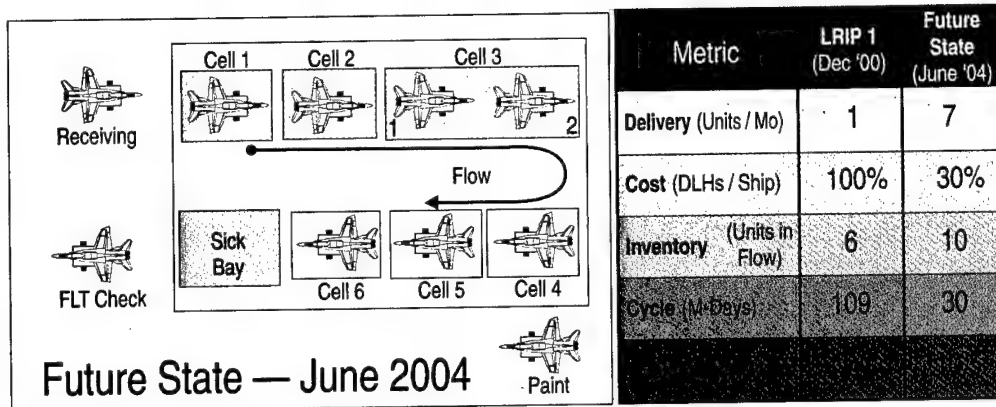


FIGURE 5.

T-38 FUTURE STATE LAYOUT AND VALUE STREAM PROJECTIONS

Figure 5 pictorially represents the 3P defined future state facility layout with supporting value stream analyses.

The 3P event and subsequent value stream analyses clearly indicated implementing Lean would result in benefits consistent with the customer's desire to reduce program cost and delivery risk. Boeing leadership, with customer support, chose to accelerate the original SOW Phase II (Planning) and Phase III (Implementation) activities.

Based on the projected future state value stream performance, the Williams Gateway Production Facility accepted the challenge to accommodate the increase in rate 4 to 7 aircraft per month (September 2001 through May 2002) and transform the facility from stationary docks to Lean production cells pulsing at TAKT without increasing production workforce headcount.

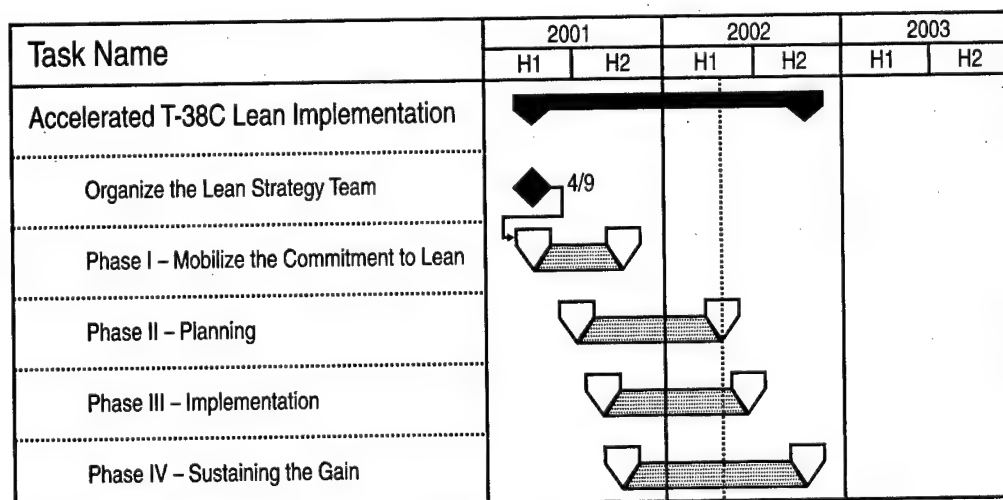


FIGURE 6. ACCELERATED LEAN IMPLEMENTATION

Early in Phase I, Lean practitioners deployed 6S (5S plus Safety). Immediate performance gains were realized that facilitated the time production personnel were committing to training and Integrated Product Team (IPT) meetings.

Accelerating the Lean implementation phase reduced the transition-planning span and forced a parallel path with implementation. (See Figure 6.) The key to successfully deploying this strategy was employee involvement. Personnel assigned to the production Lean cells met one and one-half hours daily over a period of five weeks with engineering (industrial, manufacturing, liaison), support functions (quality, safety, supply, facilities, business operations, information technology), and management to reorganize work content and precedence, define work cell layout and facility requirements, and set performance goals. (See Figure 7.) The IPT environment, where all parties were stakeholders in Lean cell performance, was critical to meeting the aggressive Lean cell implementation schedule.

THE RESULTS

The health of a Boeing Lean Enterprise Production is measured in the context of five Interdependent Performance Metrics; specifically, Delivery, Cost, Inventory, Cycle, and Quality. Figure 8 quantitatively compares the impact of implementing Lean at the T-38 AUP facility. Low Rate Initial Production (LRIP) 1 values reflect the algebraic average for each performance metric for the first 15 upgraded aircraft produced. The Lean Baseline values reflect the algebraic average for upgraded aircraft delivered in September 2001, prior to deploying any Lean initiatives at the production facility.



FIGURE 7. INTEGRATED PRODUCT TEAM (IPT) MEETING

Metric	LRIP 1 (Dec '00)	Lean Baseline (Sept '01)	Current Status (Aug '03)	Future State (June '04)
Delivery (Units/Mo)	1	4	7	7
Cost (DLHs/Ship)	100%	87%	37%	30%
Inventory (Units in Flow)	6	14	10	10
Cycle (M-Days)	109	64	30	30
Quality (Defects/1K Hrs)	NA	25.3	15.3	10.5

FIGURE 8. T-38C VALUE STREAM PERFORMANCE COMPARISONS

The Current Status metric values reflect the algebraic average for upgraded aircraft delivered in August 2003. The Future State metric values represent the value stream values projected during the July 2001 3P event.

The T-38C Program is well on its way to achieving its future state goals supported by a culture committed to continuous improvement.

Figure 9 presents Direct Labor Hours for delivered upgraded aircraft during the transition to a Lean production system pulsing at TAKT. For reference, an 85 percent learning curve, upon which the production operations were planned, is presented as a trend line. For comparative purposes, Pre- and Post-Lean implementation performance trends are provided.

The noteworthy improvement in DLHs per delivered upgrade is directly attributed to supporting an increase in rate without increasing production center headcount. This accomplishment was made possible through the elimination of the inherent waste associated with the craft/mass assembly production system and its accompanying support systems. The benefits of Lean would be short lived if the concept were simply based on driving the work force to work longer and harder rather than smarter.

Figure 10 reinforces the concept that increased efficiency was achieved through waste elimination. Data plotted on the dual axis graph are the Overtime Plan Target at 6 percent of total production hours (dashed line), percent overtime expended by month to deliver aircraft (vertical bars), and the customer demand by month (solid line). The times each Lean production cell began operation are superposed on the graph and represented by vertical lines.

The workforce was held constant during the period of time when production rate increased from 2 to 7 aircraft per month and the Lean production cells began operations. The overtime trend followed the rate increase until all Lean cells were operational. Overtime rate has remained constant at 2 percent.

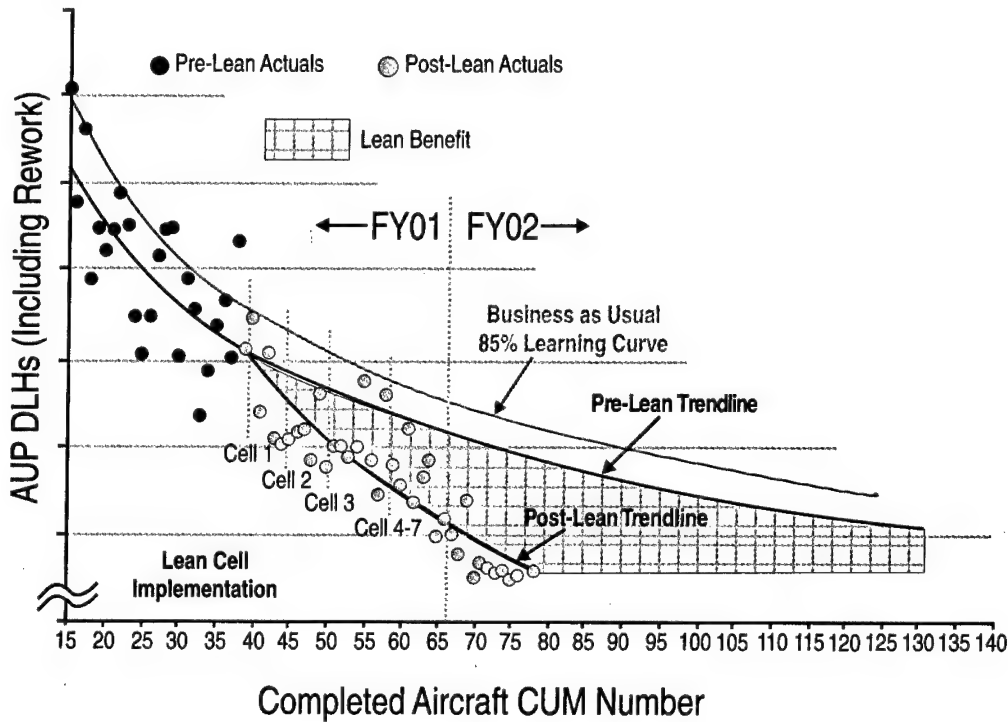


FIGURE 9.
DIRECT LABOR HOURS FOR COMPLETED A/C
DURING LEAN TRANSITION

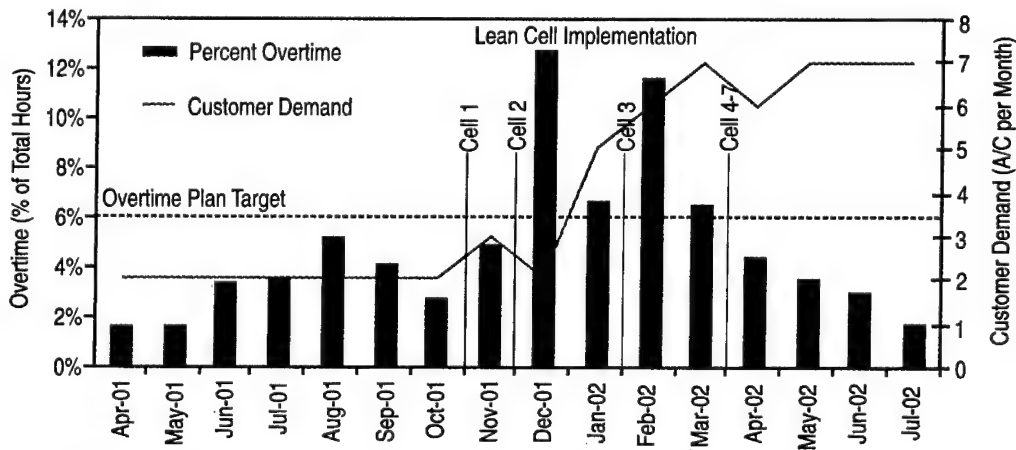


FIGURE 10. OVERTIME PERFORMANCE DURING LEAN TRANSITION

LESSONS LEARNED

Implementing Lean principles is synonymous with changing workforce culture. The workforce, both factory and non-factory alike, perform best when they claim ownership and accountability for their own actions and that of their team. Extending responsibility, authority, and accountability to self-directed work teams (within bounds) invigorates the workforce and fosters creativity. A workplace where everyone's opinion is valued equally and teams are recognized and rewarded for excellence will continuously improve. A successful transition to a Lean enterprise production system is as much about the people and culture transition as it is production flow and reconfiguring brick and mortar.

Implementing Lean principles is a continuous journey. Remain flexible and support adaptive processes. Today's good idea will be replaced by tomorrow's creativity and improvements in technology in an environment of continuous improvement. The T-38C Production System future state was barely 2 years old before it had gone through two significant refinements. The subject matter experts participating in the original 3P event were unable to envision the realm of today's possibilities. It is as if they had to travel down the road of employee involvement and around the corner of continuous improvement before they could see where and how far they could go.

Implementing Lean principles is not free. Training and a willingness to invest in adaptive processes capable of supporting single piece continuous flow TAKT based production are required. However, as much as 90 percent of the system improvement can be accomplished with minimal capital investment. Experience has shown that most Lean initiatives easily surpass a 4.0 return on investment threshold.



David D. Ott began his aerospace career in structures technology with a passion for designing for manufacturing and assembly. His background in definition engineering, materials research, and implementing quality and cost improvement initiatives provides a foundation to guide Lean Implementation throughout the product value stream. As a Lean Enterprise Implementation Specialist, Ott targets improving factory and non-factory processes in order to realize gains in quality and reduced cycle and cost.

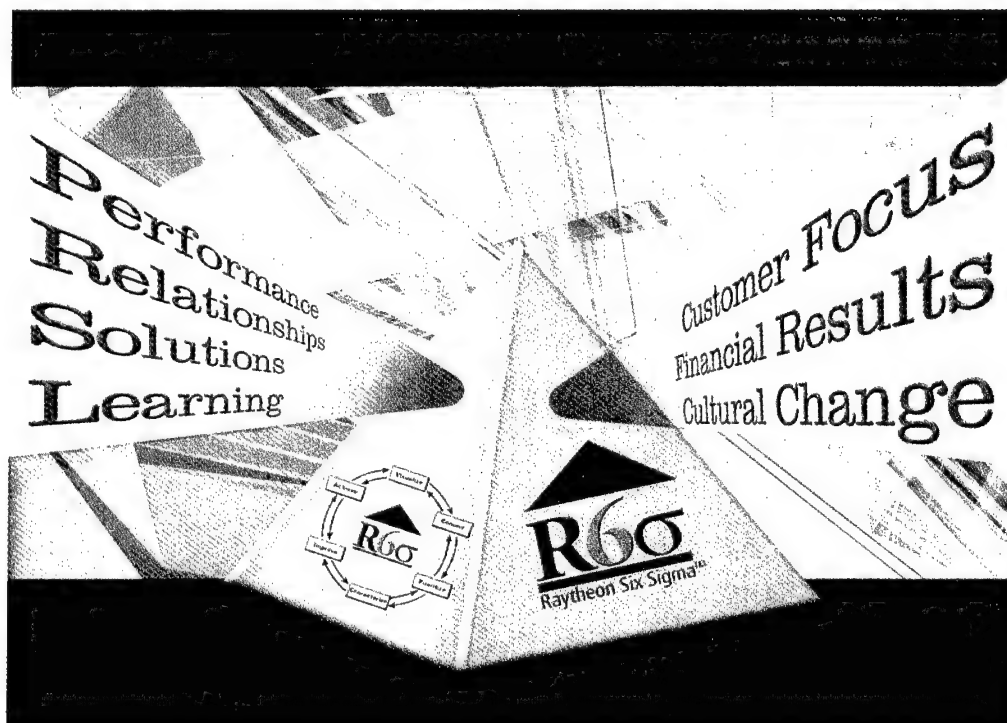
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James B. Davis was trained in Kaizen, or continuous improvement, by protégés of Taiichi Ohno, and considers himself to be a student of Lean, seasoned by the school of hard knocks. Recent assignments include Industrial Engineering, Production Support, Process Redesign, Program Management, and Lean in both Commercial and Defense businesses. Davis has a bachelor's degree in finance and economics from Ohio State University, and a master of business administration in international business from Duke University.

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AUTHOR BIOGRAPHIES



RAYTHEON— NEW CHALLENGES, NEW SOLUTIONS, AND DOCUMENTED RESULTS

BOB BLAIR AND JON MCKENZIE

Born from a multi-billion dollar debt and a driving commitment to customer success, Raytheon Six Sigma™ (R6σ™) has generated over \$2 billion in financial benefits resulting from over 3,000 projects. The culture change is now part of the fabric of Raytheon, with over 21,000 specialists, 1,200 experts, and 50 master experts guiding 76,000 employees to customer success. Raytheon Six Sigma™ is now an integral part of the business strategy and is successful because it focuses on achieving success for customers while delivering results for the company. Guarding against complacency, Raytheon leadership ensures that R6σ™ continues to evolve with the changing needs of the business. This paper highlights how R6σ™ was used to forge a culture of customer focus and productivity improvement that led to higher levels of financial stability and customer success.

Raytheon's initial focus for Raytheon Six Sigma™ (R6σ™) was to address debt—the company's *Burning Platform*. Early on, leadership took ownership of R6σ™ by creating an initiative that was unique to Raytheon. This early work created *ownership* for this business strategy and led to investment in R6σ™ infrastructure and learning throughout the organizations. Soon after R6σ™ Experts started working projects in the business, teams were delivering results that reduced debt and changed the corporate culture. Raytheon leaders were delighted with these initial success stories and internalized how R6σ™ could be used to tackle their next set of business challenges and achieve the goals of the organization.

As use of R6σ™ in the organization became widespread and goals were achieved, a higher level of performance became the expectation. As the bar was raised for

business leaders, R6σ™ needed to raise the bar as well. As a result, businesses increased focus on working R6σ™ projects *with the customer for the customer* as well as embedding use of it in product development. The case studies provided later illustrate two examples of projects in these areas.

The fact that the R6σ™ initiative continues to evolve, and has prospered with a change in Executive Leadership, indicates it is not the *program* of the day at Raytheon. It continues to be the business strategy of choice.

THE JOURNEY BEGINS

During the 1990s, Raytheon acquired the defense businesses of E-Systems, Hughes Texas Instruments, and others. While adding to the business base, these acquisitions had driven Raytheon's debt to \$9 billion by early 1999. It was a business imperative to reduce the debt costs as well as to improve cash flow.

Raytheon initiated Raytheon Six Sigma™ in late 1998. It leveraged the best approaches from *legacy* companies with the vision for Raytheon. Raytheon Six Sigma™ was developed by benchmarking other companies and leveraging best practices internally. An internal team, supported by a consortium of external experts, worked to explore approaches and to define a strategy unique to Raytheon. Dan Burnham, who had just become the new CEO, guided the team and planned to bring the company together by embedding Raytheon Six Sigma™ into the fabric of the organization. His Vision was to:

- Make customer success a strategic focus for the company.
- Increase productivity.
- Transform the culture.
- Grow the business.

Figure 1 shows the integrated business strategy that emerged and brings together the following key areas:

- **Customer Focus:** Customer satisfaction is the top priority. Understand each customer's culture and needs. Focus on activities that add value to their products and eliminate those which do not. Build lasting relationships and anticipate customer needs to achieve a competitive edge. Be the supplier of choice.
- **Tools:** Identify the constraints and high leverage opportunities through the Business Diagnostic process. Combine the statistical process analysis techniques of traditional Six Sigma with the *Lean* manufacturing approach to eliminate waste and non-value added activity. Provide the right analytical tools for each situation.

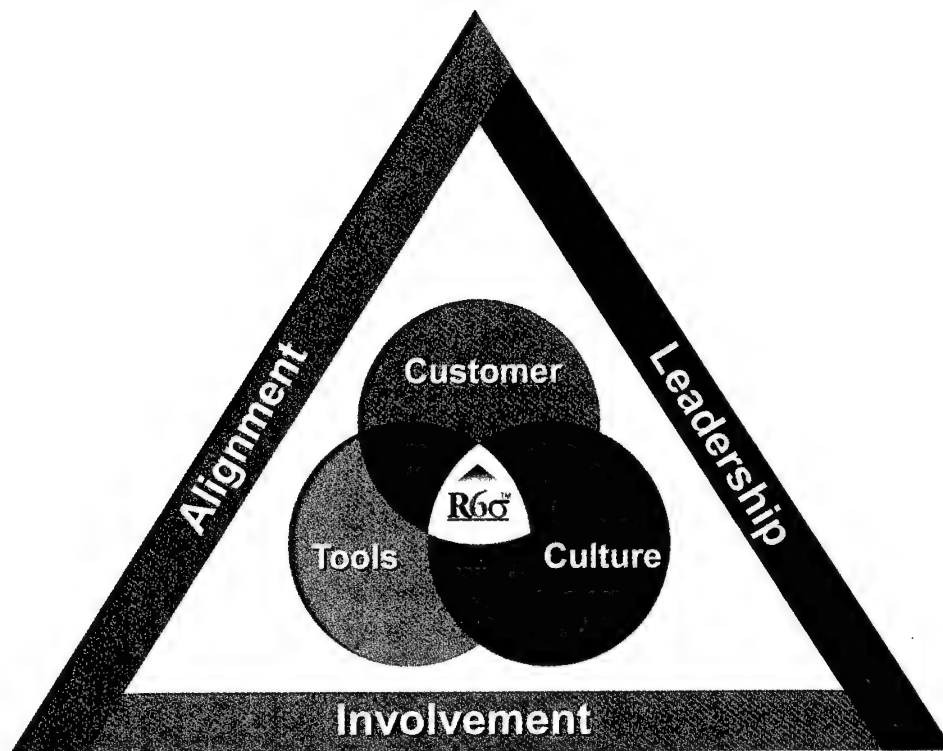


FIGURE 1.

RAYTHEON'S SIX SIGMA (R6σ™): AN INTEGRATED BUSINESS STRATEGY

- **Culture:** Transform the corporate culture to embrace a process improvement/measurement focus, teamwork and empowerment. Shift from valuing functional behavior to adopting a business/customer focus.

The following important elements were also incorporated into the R6σ™ deployment strategy:

- **Alignment:** Ensure company leadership understood and are committed to the R6σ™ strategy before deploying techniques to the workforce.
- **Involvement:** Get all company employees informed and motivated. Make R6σ™ a way of life that touches everyone.
- **Leadership:** Demand leadership involvement and accountability at every level to make R6σ™ the focus of their operations.

Many companies have used Six Sigma, Total Quality Management, Quality Circles, or similar approaches with varied results. Experience gained from these initiatives highlighted the need for R6σ™ to require leadership and workforce involvement, commitment and ownership. Five days of Leadership Education for 1,200 of Raytheon's

leaders stimulated discussion and debate as to why they needed this initiative, what they needed to do as sponsors in their businesses, and how they would behave and act differently.

The results from this significant investment were measured in each leader's actions and the results achieved. They dedicated resources to deployment in their organization, invested in additional training for their mid-level managers (over 7,000 mid-level leaders attended 2.5 days of training), selected their best people to become R6 σ TM Experts, and sponsored projects in their organizations. Project work was initiated in each business and cash was generated to reduce the debt. Support for the business came from corporate resources that were allocated to develop and deliver training for Experts, implement corporate-wide Communications programs, and create and implement an R6 σ TM Human Resources toolkit.

STRUCTURED FOR SUCCESS

Determined to create the environment for success, Raytheon leadership ensured that every level of the company was engaged in R6 σ TM development and deployment. Deployment started with corporate leadership *walking the talk*, with full support throughout the organization.

IMPLEMENTATION ROLES

- **Raytheon Corporate Leadership Team:** Sets the vision, approves planning, removes barriers and tracks progress.
- **Businesses:** Business leaders work daily with their Master Experts to integrate R6 σ TM into their operations and business strategy process. Approaches are tailored to each business' needs and situations.
- **Raytheon Six SigmaTM Council:** Chaired by the Vice President of R6 σ TM and comprised of Master Experts from each business and corporate functional office; the Council ensures corporate consistency, coordinates plans, schedules and resources, communicates the vision, expectations and experiences, and builds/sustains momentum.

Successful deployment also required individuals with the knowledge, skills, and behaviors essential to being a successful change agent. Business leaders selected their best candidates and dedicated them to R6 σ TM in roles that accomplished the goals of the business and in assignments that would offer opportunities for growth. The roles include:

- **Master Expert:** Full time highly experienced and trained leaders who integrate R6 σ TM planning, training, mentoring, and highly complex projects within their organizations. Directs reports to business and functional leaders.

- **Experts:** Full time individuals trained to lead complex projects and train/mentor others in R6σ™ activities.
- **Specialists:** Individuals trained in basic R6σ™ concepts and productivity improvement skills to transform their work areas.

KNOWLEDGE AND SKILLS

A framework for deployment was needed to ground the Leadership, Experts, and Specialists in a set of principles, a definition, and a process. In every training session these basic tenets of R6σ™ were presented and then applied by each new project team. Experienced Master Experts or Experts were assigned to coach all Expert-led and Specialist-led projects to reinforce learning and ensure successful completion of their projects. Project work focused on meeting the corporate goals and business operating plans while focusing on making a difference for customers.

"Determined to create the environment for success, Raytheon leadership ensured that every level of the company was engaged in R6σ™ development and deployment."

THE PRINCIPLES

Each project team used the guiding principles listed below:

1. Specify Value in the Eyes of the Customer (Work on projects that will deliver outcomes desired by the Customer.)
2. Identify Value Stream and Eliminate Waste/Variation (Ensure teams understand the current reality, have identified the undesired outcomes and effects, know the root cause, and create solutions that are within the boundaries established by leadership.)
3. Make Value Flow at the Pull of the Customer (Deliver what the customer wants, when the customer wants it.)
4. Involve, Align, and Empower Employees (Ensure all employees have the knowledge and skills to be involved and know where they can add value/make a contribution.)

5. Continuously Improve Knowledge in the Pursuit of Perfection (Ensure teams are continuously striving to take the next step and never stop striving for perfection.)

DEFINITION

Leadership created and communicated the definition of Raytheon Six Sigma™ throughout Raytheon: *Raytheon Six Sigma™ is a knowledge based process that we will use to transform our culture in order to maximize customer value and grow our business.*

The definition captures the essence of the strategy: Deliver customer value (satisfaction), transform the culture, and grow the business. The *knowledge-based process* refers to Raytheon's unique six step process—visualize, commit, prioritize, characterize, improve, and achieve—to identify and accomplish productivity improvements to make customer satisfaction and business growth a reality.

THE R6σ™ SIX-STEP PROCESS

The six-step process is iterative (arrows go both ways) and is graphically in Figure 2.

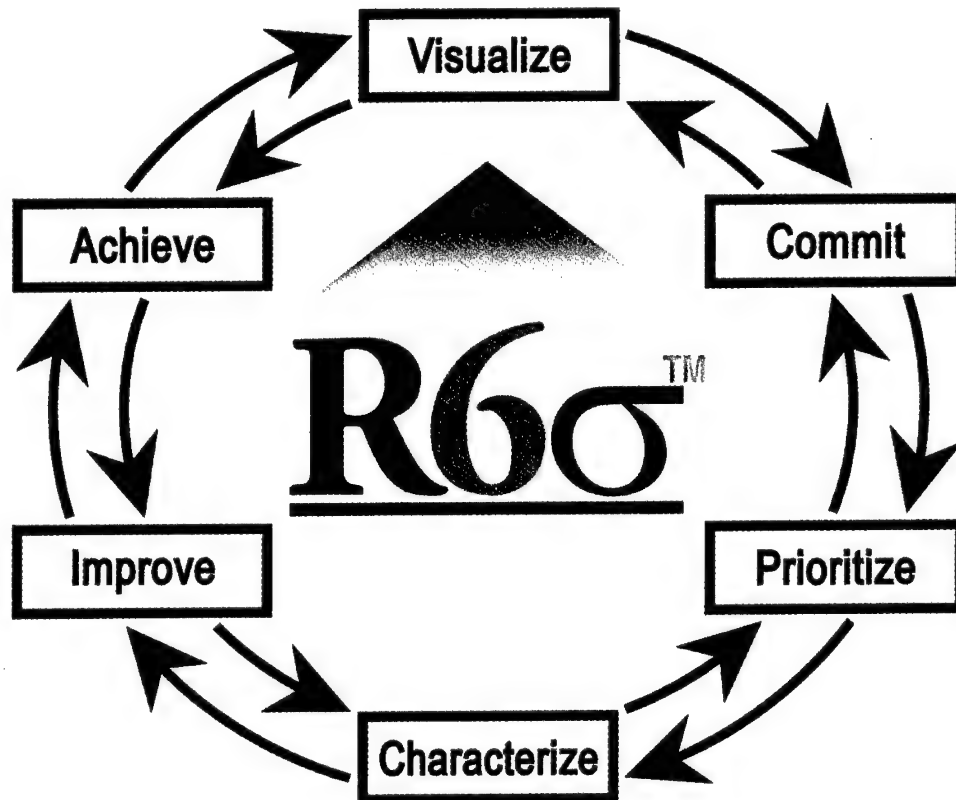


FIGURE 2. RAYTHEON SIX SIGMA™ (R6σ™) SIX-STEP PROCESS

This process starts with the creation of a clear vision of the future with a clear and pressing need for change. The vision focuses the project team on the goal and business need.

Next, the Commit Step is required. The Commit Step ensures the project has the necessary support from business leaders. This step is a go/no-go point in the process, and project teams do not progress to prioritize until they have a committed sponsor and team aligned with the vision. The process is iterative and some teams will be asked to return to previous steps.

"Throughout the journey, leadership ensured that all project teams understood the important linkage between customer success and financial results."

After Commit, the next step in the process is Prioritize. Using facts and data, project teams will discover improvement opportunities and understand organization readiness for change. At this time, resources needed to work the project are identified and initial return on investment (ROI) estimates are completed. Teams will use this analysis to prioritize the highest leverage projects necessary to achieve goals. Those projects offering the highest returns will be scoped and resources are assigned to work project(s) that will make the most difference to the customer and business. Teams will typically revisit *Commit* with the project sponsor to ensure they remain aligned with the business needs and goals.

Next, the process teams characterize and define their understanding of the current state performance: identify opportunities, develop potential solutions, conduct tradeoffs, and create a plan for improvement. The results are reviewed prior to implementation of the improvements. The Improve Step in the process completes the detailed design and implementation of improvements and control systems necessary to sustain the change. For example, this step delivers new operating instructions, training, capital equipment and facility changes, process changes, and most importantly, value for the customer.

The Achieve Step in the process delivers the sustainable, measurable results to build momentum for continuous improvement. The project team leader(s) ensure all team members are recognized and celebrates success. Project results are publicized to share lessons learned and to motivate others to join the R6σ™ Journey.

SUCCESS FOR OUR CUSTOMERS: SUCCESS FOR THE BUSINESS

Throughout the journey, leadership ensured that all project teams understood the important linkage between customer success and financial results. Raytheon business leaders ensured in their communications that they did not lose sight of the Raytheon mission to ensure customer success through delivering products that meet end user needs. Leaders also focused project teams on the business need to deliver financial returns. These teams needed bottom line results to:

- Develop new products.
- Conduct essential independent research and development.
- Create customer solutions.
- Bid on new opportunities.

By the end of 2002, debt was successfully reduced from \$9 billion to \$7.4 billion. Four years into R6 σ TM Raytheon had exceeded the initial goals for the program, and the infrastructure was in place to take R6 σ to another level. This infrastructure continues to strengthen monthly with completion of projects, Expert and Specialist training classes, and Master Expert selection. R6 σ TM infrastructure, as characterized by the number of resources available to work projects, now includes 30 percent of Raytheon employees. Financial benefits to the corporation are estimated at approximately \$1 million per full time Expert per year.

"As R6 σ TM success stories started to pour out of the company, identifying ways to make customers successful using R6 σ TM has become the standard for Raytheon to manage its business."

THE NEXT LEVEL

As R6 σ TM success stories started to pour out of the company, identifying ways to make customers successful using R6 σ TM has become the standard for Raytheon to manage its business. Leadership enthusiastically celebrated past project work that delivered greatly reduced operating costs and debt; increased customer satisfaction; and created a dynamic company culture that embraced change, empowerment, and

process improvement. The results achieved reset business leader expectations and R6 σ TM resources were refocused on growth and creation of new products. Changing business needs were again reflected in Annual Operating Plans, Goals, and in the continued evolution of R6 σ TM.

To meet these changing business needs and expectations, R6 σ TM training was also changed to feature discovery learning, debate, and case studies. New classes were also opened to all Raytheon employees and designed to deliver training in context with project work requirements. The new classes cover in-depth, analytical knowledge based tools, and robust design methods and techniques for teams supporting Product Development Design for Six Sigma (DFSS), Integrated Supply Chain, Business Operations (Information Technology, Finance, Human Resources, etc.), Program Management, and Marketing. This context-specific training provides more employees with the opportunity to add depth to their R6 σ TM knowledge and skills.

"Sharing lessons learned and best practices is encouraged at periodic Expert forums and celebrations where project teams brief project work, hear guest speakers, and network with other project teams."

PROJECTS DELIVER RESULTS

Project teams deliver the desired outcomes for customers as well as the corporation and use of knowledge sharing to accelerate application of R6 σ TM has become a part of the culture. Sharing lessons learned and best practices is encouraged at periodic expert forums and celebrations where project teams brief project work, hear guest speakers, and network with other project teams. The R6 σ TM Project Library now includes a database of over 3,000 projects and is searched on a regular basis by teams interested in jump-starting their project work by learning from others. Project teams also learn through participation in Communities of Practice, benchmarking, and regular communication with other teams working similar projects.

The case studies described below are incorporated in the knowledge base and are used to illustrate examples of successful projects. These projects are two of the 3,000-plus projects that have delivered business results since 1998. The teams who worked these projects were all trained to apply the R6 σ TM principles, process, and tools to support completion of their project work.

CASE STUDIES

The cases are short descriptions of the project work completed on the Global Hawk program and Design for Six Sigma in the Raytheon Missile Systems organization.

GLOBAL HAWK

The Challenge

Theater Commanders conducting Operation Enduring Freedom needed the real time intelligence that was available from the new Global Hawk system. The Air Force needed completion of Engineering and Manufacturing Development for the Global Hawk Integrated Sensor Suite 6 months early—7 months shorter than the 13-month development time.

Background

Global Hawk is a high altitude, unmanned, aerial vehicle system designed to provide real time intelligence to theater commanders. Raytheon produces the integrated sensor suite and ground stations as a subcontractor to Northrop Grumman. Technology demonstrations were ongoing when the September 11 tragedy accelerated the need for an operational system. The goal was to turn a technology demonstrator into a deployable system that supported the troops and saved lives.

A full-time R6 σ TM Expert was recruited to lead the project team. Team members were assigned actions to gather data and used interviews and a Quality Performance Indicator¹ (QPI) tool as the assessment methodology that set the baseline for understanding the current situation. This first step allowed everyone on the team to baseline current state and measure progress toward the goal. Next, the data were analyzed to identify the constraints, establish priorities, and create solutions that would achieve the project goals. From the analysis came the following prioritized solutions:

- Define clear roles, responsibilities, and accountabilities.
- Establish lines of communication with the customer.
- Create program run rules.
- Develop the risk management plan and tracking metrics.
- Post *radar* chart² used to measure communication improvements.
- Move to a contributory team culture.

The team also used Critical Chain Project Management³ techniques to accelerate the schedule. Subject matter experts, in conjunction with the Customer and Program Team, used reverse planning to develop workflow plans, identify unrealistic task completion

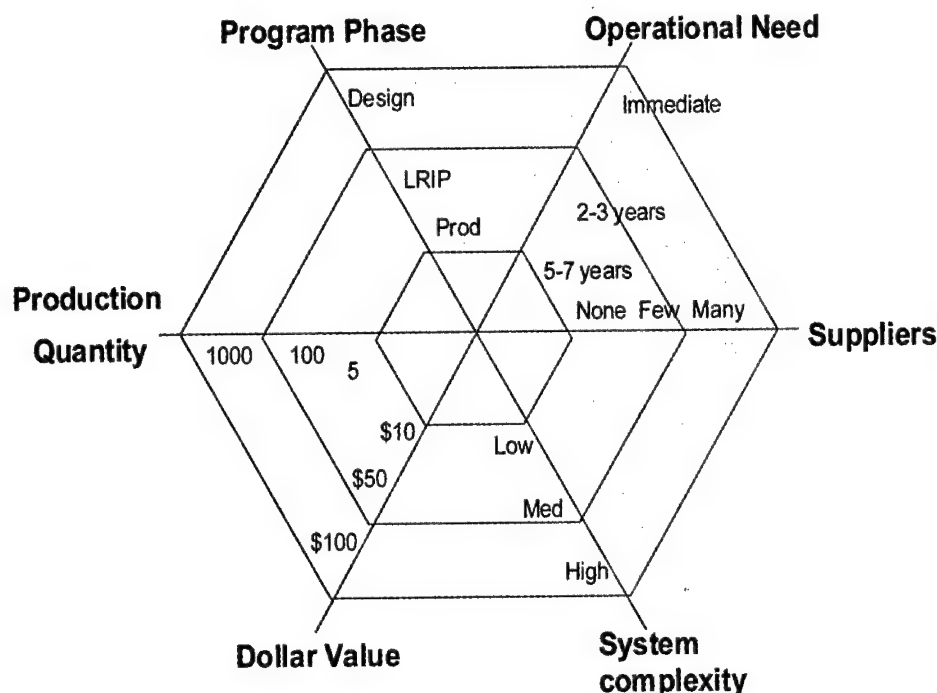


FIGURE 3. EXAMPLE OF A RADAR CHART

expectations, address opportunities to improve information flow, and identify resource constraints. Run rules were established to optimize the use of the critical resources and inch-stone charts were used to monitor progress. Sensitivity to the existing culture dictated use of workshops that addressed the staff mindset and focused them on the goal. When everyone agreed that the teams were committed and ready, changes were implemented such as daily stand-up meetings used to identify any barriers and assign actions.

Results

Delivery was completed 6 months ahead of schedule. The customer achieved the outcomes needed when this mission critical asset was delivered to the Theater Commanders. Additionally, production costs were reduced and customer satisfaction and focus was improved. The Raytheon team was able to capture follow-on business, increase profits, and improve cash flow. The team's focus on changing the culture, keeping the customer involved, and sensitivity to resistance to change was essential to delivering a system in half the scheduled time.

DESIGN FOR SIX SIGMA

The Challenge

Raytheon business needs have evolved since initiating R6σ™ in 1999 and project teams needed to evolve as well. As project results were achieved, the importance of

DFSS⁴ became evident. More robust design processes were the long-term solution to increase customer satisfaction and further improve Raytheon financial performance.

Raytheon Missile Systems has been implementing DFSS and provides the following insights and challenges to others interested in DFSS deployment.

Background

Raytheon's application of Six Sigma tools during development can be traced to the AIM-9X Sidewinder Missile Engineering and Development program. In 1995, through the application of Cost as an Independent Variable (CAIV), a reduction of \$1.2 billion in AIM-9X Life Cycle Costs was achieved. Particular emphasis was placed on the cost of the Raytheon-supplied Integrated Detector Assembly (IDA) using Design of Experiments⁵ (DOE) and other variability reduction techniques. By 1998, success on this program and others resulted in the Navy recognizing Raytheon's CAIV process as an industry best practice.

***"IPDS is the systems engineering methodology
by which Raytheon manages, develops,
and produces products."***

The joint Air Force/Navy AMRAAM missile Phase III program, started in 1998, also implemented CAIV. Through the application of Quality Function Deployment⁶ (QFD) and Design for Manufacture and Assembly⁷ (DFMA) workshops (and other efforts) a reduction of 20 percent in Average Unit Production Cost (AUPC) of the missile was achieved. Phase III incorporated Electronic Counter-Counter Measures (ECCM), an upgraded seeker, and longer range capabilities into AMRAAM. Over 25 QFD/DFMA workshops were conducted with Air Force customer participation. Involving the supply chain, key supplier workshops with circuit card manufacturers Kuchera and Group Technologies resulted in 15 percent reductions in circuit card count and electronics cost.

Building on this Success

As a result of these and other early successes, Raytheon is now integrating a suite of Six Sigma tools into a structured methodology and incorporating them within the Integrated Product Development System (IPDS). IPDS is the systems engineering methodology by which Raytheon manages, develops, and produces products. It fosters use of a consistent process across all Raytheon programs. IPDS is divided into stages along the life cycle of the business. DFSS focuses on the early stages of the life cycle—business capture, requirements and architecture, product development, and system integration.

DFSS delivers the most return if implemented at the front end of a program and is consistently applied throughout the system life cycle. One of the new development programs that will be piloting Raytheon's DFSS methodology is the Army's Non-Line of Sight Launch System (NLOS-LS) Precision Attack Missile (PAM). The NLOS-LS PAM, a low-cost direct attack missile with variable-thrust propulsion, has a range of 40 to 60 kilometers and will be developed by Raytheon. Aerojet, the variable-thrust propulsion supplier, will be a key participant in DFSS, as will Army customer representatives.

Implementation of DFSS

While Raytheon's application of Six Sigma tools to the development process is not new, the structured methodology being integrated into their IPDS will allow the toolset to be consistently deployed across the corporation. A DFSS practitioner course has been deployed to teach engineers and program managers the tools and techniques to establish it as the way that Raytheon does its business. Customer benefits from DFSS include improved affordability, higher quality, and continued performance excellence.

Raytheon will create high performance, affordable products through the application of Six Sigma tools during the development phase.

FACTORS FOR SUCCESS

Raytheon's implementation experience continues to grow and the following factors provide the summary to date of the key factors that contributed to Raytheon's success. This list continues to grow and be refined as Experts and Specialists refine their skills.

Key Success Factors

1. Focus on customer success and allocation of ample resources.
2. Set goals and vision to challenge the organization.
3. Leadership commitment: leaders must be knowledgeable, informed, and involved.
4. Involve everybody, not just an elite few. Ensure active participation of *legacy* talent. Ensure customer and supplier involvement.
5. Use empowerment, intensive communication, education, and training.
6. Identify and work on the constraints.
7. Apply the right tools at the right time.
8. Consider the culture and organization readiness for change—address the barriers and change the culture first.

9. Evolve the approach to meet the changing needs of the business. Never stop learning and working toward perfection. Complacency will result in a temporary plateau before the inevitable slide downhill.
10. Measure and reward results. Celebrating success will lead to more success.

SUMMARY OF RAYTHEON'S APPROACH

Raytheon Six Sigma™ continues to evolve as the needs of projects and Raytheon change, but the focus on customer success as the central mission to R6σ™ has never wavered. The journey has been successful at Raytheon because R6σ™ balances achieving success for customers as well as delivering financial benefits to the corporation. Bill Swanson, who became Raytheon's chief executive officer in July 2003, is now guiding it. Swanson is currently leading Raytheon Six Sigma™ by shaping the strategy and applying his in-depth knowledge and experience with the defense industry to evolve R6σ™ to meet future challenges for customers and in product development. As Raytheon changes to meet new customer needs and competitive pressures, R6σ™ has the leadership, the vision, and the agility to change with it.

R6σ™ is a trademark of Raytheon Company.

ENDNOTES

1. Quality Performance Indicator (QPI) is a consistent, predictive indicator of the risk of achieving a project's quality product. The QPI uses project specific criteria and weightings established at program start-up. It is closely aligned with the integrated product development system, and assessment of the Program is conducted monthly and reviewed at key milestones. The QPI measures contract compliance, customer satisfaction/expectations, deliverable product performance, and program plan implementation, results of quality evaluations, rework, and product/mission assurance involvement.
2. Radar charts are assessment tools used to evaluate and prioritize using multiple criteria and are useful to show the gaps between current organization performance and the vision. This example may be useful to assess project priorities in a program office. Get multiple perspectives on each project measured using each axis on the radar chart. Connect the ratings and evaluate priorities. Results from this example could be used to best allocate scarce acquisition management resources across multiple programs.
3. *Critical Chain Project Management and Buffer Management* is a proven *whole system* approach to project management that does not rely on managing a project based on a series of supposedly *safe* task estimates. A project schedule can now be designed to protect the project due date by taking *safety* that was spread among the tasks and concentrating it where it does the most good—as buffers at the end of the critical path and where others paths feed that critical path. Implementations of *Critical Chain Project and Buffer Management* typically result in project schedules that can be 15 to 25 percent shorter than traditional schedules but with considerably more reliability of the promised final project due date with less chaos and rescheduling.
4. Design for Six Sigma (DFSS)—This strategy for product development uses a wide range of tools and methodology to provide project management, executives, and engineers the data, risk measures, and design deliverables for each gate in the integrated product development process. The focus is to develop products that are highly valued by customers. DFSS identifies and focuses on critical parameters in the design to ensure delivery of a product that delivers the desired customer outcomes and is compatible with the company manufacturing capabilities and processes.
5. Design of Experiments—A systematic and efficient way to simultaneously investigate causes of variation in a process. Statistical analysis techniques are used to identify those factors and their interactions that best control the output of a process. The goal is to find the optimal factor settings from among many potential factors to achieve the output goal (e.g., improve performance characteristics, reduce cost,

reduce cycle time, reduce variation, increase yield, increase sales, and increase the impact of communication). Both expected output value and variation in the output could be modeled using this technique. Through the analysis of many factors, this technique prioritizes the few factors that make the most impact to the end goal. This technique has been successfully applied in engineering, manufacturing, and business operations situations.

6. Quality Function Deployment—This is a method for translating a customer's wants and needs into company requirements for deployment throughout all aspects of the business including product development, engineering, manufacturing, and marketing. It is used to determine which aspects of the product or service are most important to the customer and ensures critical performance parameters are addressed. It provides users with a systematic and structured process for translating the Voice of the Customer (VOC) into appropriate requirements and actions.
7. Design for Manufacturing and Assembly—This process focuses on cycle time reduction at the manufacturing stages, and improving producibility and maintainability. The approach develops a *teaming* philosophy between Design Engineering and Manufacturing Engineering when a product is being designed. The cross-fertilization that occurs between the functions of design and manufacturing results in tremendous benefit in improved producibility, improved yields, and cost reduction. In more mature teaming environments, assemblers and operators on the manufacturing floor (even suppliers) participate in these design/manufacturing teams. Therefore, the key to success is to set a goal that the team can agree upon, focusing on simplicity that meets the design requirements.



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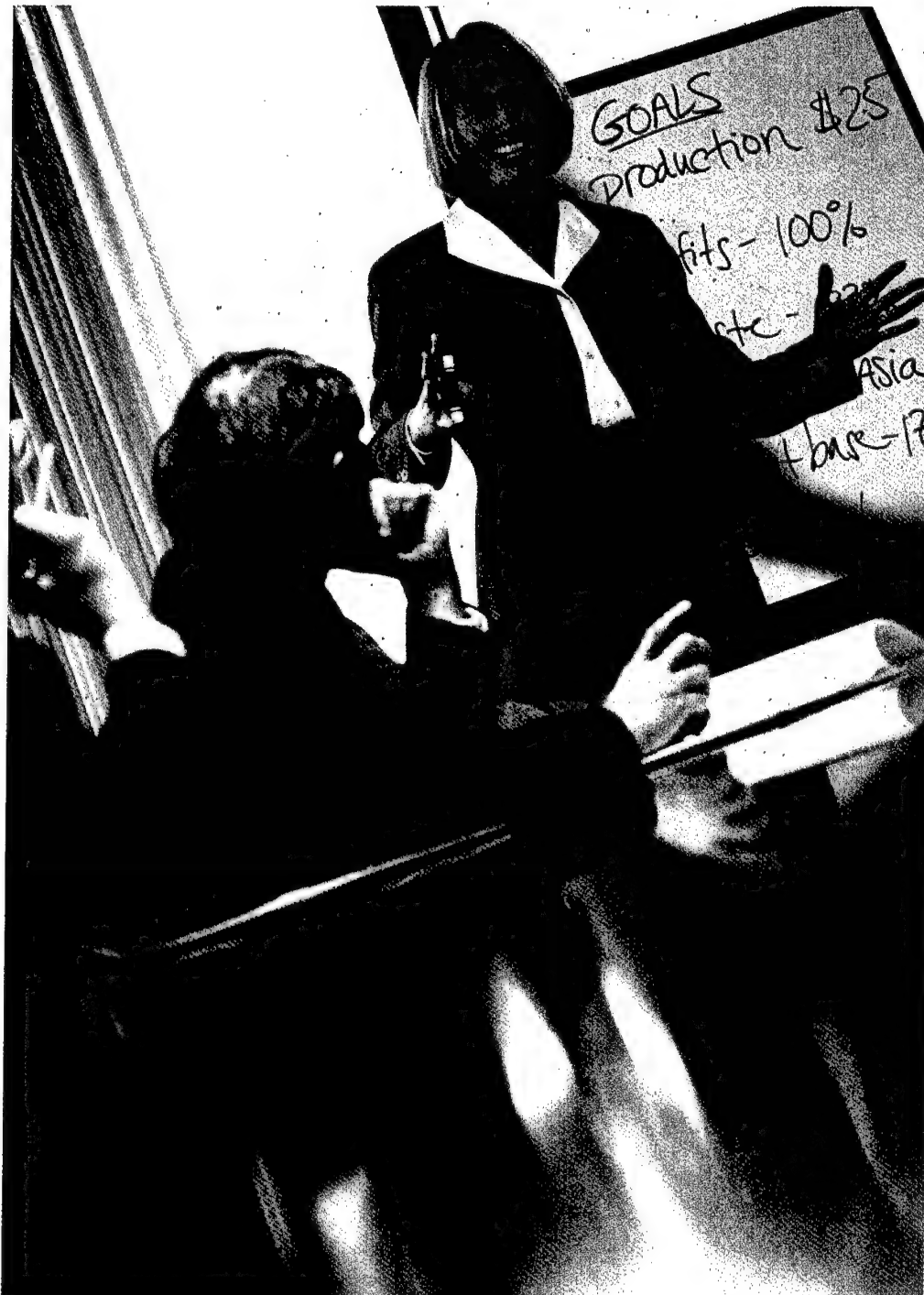
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TAMING THE AEROSPACE SUPPLY CHAIN— A CASE STUDY IN ORGANIZATIONAL INTEGRATION

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Integrating suppliers and customers to capture supply chain efficiencies and effectiveness is critical in today's increasingly competitive environment. However, knowing this and doing it are two different matters. The methodology described here is an effective means to develop inter-organizational coordination. To achieve this coordination companies must first be made aware of the fundamental dynamics of supply chains. Awareness can disengage the individual personalities within different organizations and allow members of the supply chain to objectively view their value stream. Then, the individual organizations can define and measure the current state of their supply chain and finally agree to corrective actions that benefit the entire supply chain. Thus, our question is, how do firms that are traditionally isolated in their supply chain dealings introduce a greater degree of cooperation to their relationships? We will provide an answer to this question with a supply chain case study.

Integrating suppliers and customers to capture supply chain efficiencies and effectiveness is critical in today's increasingly competitive environment (Spekman, Kamauff, & Myhr, 1998). However, knowing this and doing it are two different matters. Organizations must overcome the tendency to manage their supply chain relationships strictly on the basis of power and *zero-sum* behaviors, because significant

benefits can accrue to all supply chain participants through cooperation. Thus, our question is, how do firms that are traditionally isolated in their supply chain dealings introduce a greater degree of cooperation to their relationships?

Mentzer et al. (2001) define supply chain management as, "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (p.18). This definition has two basic features: coordination both *within* organization and *across* organizational boundaries. Intuition and experience suggest cooperation within the organization will often precede cooperation across organizational boundaries. For example, a firm must develop an internal forecasting process before using such forecasts as a supply chain planning mechanism. In addition, facilitating change is often easier within four walls of one's own organization than across organizational boundaries.

"Our experience shows that overcoming competitive behaviors requires a forum, or process, for initiating a more cooperative posture."

Intra-organizational change benefits from established protocols and controls that can be used to communicate and monitor change. These protocols do not often exist between organizations, thus challenging supply chain cooperation. A mechanism is needed to level organizational capabilities in order to foster cooperation. Our experience shows that overcoming competitive behaviors requires a forum, or process, for initiating a more cooperative posture. This paper describes such a process for initiating supply chain cooperation for firms that have had a limited history of supply chain cooperation.

METHODOLOGY

This case study was conducted with three firms from an aerospace supply chain, consisting of a prime contractor, a major subcontractor, or first tier supplier (FTS), and a minor subcontractor or second tier supplier (STS). The cornerstone of the methodology is the Supply Chain Integration Workshop (SCIW), discussed later. The SCIW was the first time representatives from all three firms gathered in one place. The workshop's objective was to facilitate cooperation across the supply chain segment by identifying and resolving inefficiencies within and across the firms. In addition to the workshop, data were collected via surveys and interviews with key personnel.

The supply chain segment under study manufactures and delivers a major component (MC) on a weapon sold to the Department of Defense (DoD). As of March 2001, the MC for the supply chain was a newly designed component in the Engineering Manufacturing Development (EMD) phase.

SUPPLY CHAIN INTEGRATION WORKSHOP

The objective of the SCIW is to bring representatives from each supply-chain tier together to begin a dialogue across the supply chain with the goal of increasing cooperation, communication, and coordination within and between companies. The SCIW is designed to motivate supply chain cooperation by demonstrating the potential for either cost savings and/or customer value enhancements. This is accomplished through a five-step process, as follows:

1. Develop an understanding of supply chain problems.
2. Baseline intra- and inter-organizational integration.
3. Identify action items for improving the supply chain.
4. Assign responsibility for executing action items.
5. Follow-up.

DEVELOP AN UNDERSTANDING OF SUPPLY CHAIN PROBLEMS

The SCIW begins with a value-stream simulation (i.e., an adaptation of the Massachusetts Institute of Technology Beer Game). The idea is to actively engage the participants on how a lack of communication and coordination across a supply chain negatively affects all members of the supply chain (i.e., the development of the whiplash effect). As is often the case, a simulation is an excellent way to begin seeing the issues that are usually too large and complex to understand within a daily context. We use simulations to motivate the workshop and form insight. For example, at the conclusion of the simulation a senior manager of the STS commented that the whiplash effect was exactly what was happening to them.

BASELINE EXTENT OF INTERNAL INTEGRATION WITHIN EACH COMPANY INVOLVED

Before companies can effectively manage their supply chain each one must have a good grasp of their individual capabilities. This is necessary so that capabilities can be matched across the supply chain. Thus, step two involves base-lining the internal and external integration within and between each participating company. This base-lining effort requires on-site data collection prior to the workshop. Without these data, it is impossible for the workshop to move beyond mere opinions and guesswork.

Our experience shows an individual firm's performance history does little for comparing performance across firms with different performance histories. That is, a firm's opinion about their performance based upon their historical baseline is irrelevant to their relative performance in the supply chain. Baseline data provide supply chain participants an ability to discuss respective capabilities through a common reference point. The capability assessment is used to discover the *gaps* in supply chain cooperation, which can be used to motivate their change or removal.

The research team administered the Lean Enterprise Site Assessment (LESA) to accomplish a thorough, objective, and accurate (valid) pre-workshop on-site assessment of each firm. The LESA was initially developed as a framework for assessing over 60 Lean implementations worldwide in 1999. Further improvements were made to the instrument and additional pilot tests were conducted to increase its validity.

"Our experience shows an individual firm's performance history does little for comparing performance across firms with different performance histories."

The LESA is an instrument that measures the extent of various Lean tools and techniques employed at a company, while also collecting key supply chain performance metrics in an effort to correlate supply chain performance with Lean infusion.¹ Tables 1 and 2 list the elements measured by the LESA. As the Tables indicate, there are several dimensions in measuring the extent of internal and external integration. For the instrument to be beneficial to the participating companies there must be a mechanism for interpreting and comparing organizational performance. An algorithm was created using the Analytical Hierarchy Process, developed by Thomas Saaty, to transform the raw data collected at each site into a summary score we call the Lean Infusion Score (LIS) (Saaty, 1980).

The LIS range from 0 to 100, with 100 representing complete Lean infusion. The overall summary score for each firm is comprised of three Lean infusion sub-scores for each of the Lean supply chain dimensions: (1) Supplier Integration Score, (2) Lean Production Score, and (3) Distribution Integration Score. The higher the score the better the company is at using Lean tools and techniques to improve its intra-firm and inter-firm integration. Figure 1 displays the LISs for each company.

Overall, none of the companies are operating on a world-class level; however, the Prime and STS appear *on the journey* and have similar infusion scores. With an overall score of 23, it appears the FTS is not as advanced with its Lean implementation as the other two companies. This is a critical insight, because the supply chain segment depends on the FTS's ability to integrate both upstream and downstream. In essence,

TABLE 1. LEAN PRODUCTION ELEMENTS MEASURED BY LESA

Lean Production Element	Definition
5S	Organization and daily maintenance of the work area.
Total Productive Maintenance	Operators are incorporated in the daily maintenance activity.
Set-Up Reduction	A concentrated effort to decrease the amount of time needed to prepare material and equipment for changing over from product to product.
Standard Work	The establishment of an optimal flow of work activities within a cell or on an assembly line.
Method Sheets	Guidelines or instructions that graphically depict standard operating procedures.
Quality Assurance	A collection of tools used to detect and eliminate defects.
Mistake-Proofing	The use of fixtures and tools to eliminate or reduce the possibility of errors.
Production to TAKT Time	Pace of demand that is used to determine the required pace of production.
Flow Cells	The grouping of product families into close proximity to eliminate unnecessary material movement.
Visual Controls	The use of visual signals to communicate information about the status of the production line.
One-Piece Flow	The ability to produce one part at a station at a time.
Mixed-Model Production	The ability to make several products on the same line in a random or sequence order.
Point-of-Use Storage	The preparation of work areas for the direct presentation of supplied materials.
Design for Manufacturing	The incorporation of manufacturing capabilities in the design phase of a product in order to make necessary engineering changes due to process capabilities before the new product reaches the production stage.
Complexity Reduction	The decreasing of parts or operations needed for a product by increasing component usage and simplifying the design.
Kanban/Pull Production	The communication system of the manufacturing environment. As materials are consumed at a downstream station, signals are sent back to previous steps in the production process to pull forward sufficient materials to replenish only those materials that have been consumed.
Kaizen Events	A focused improvement exercise during which a cross-functional team spends 1 – 3 days improving a production cell, line, or process.
Ergonomic Design	The design of processes to natural human movements, postures, and environment.
Cross-Training	The training of the workforce to perform multiple tasks.

TABLE 2. INTEGRATION ELEMENTS MEASURED BY LESA

Supplier and Distribution Integration Element	Definition
Production Development Integration	The integration of supplier design capabilities and sharing of information so as to enhance, improve, and shorten the overall product design process.
Blanket Orders	A long-term purchasing agreement that eliminates repetitive purchase orders and therefore shortens the order-entry process and significantly reduces paperwork.
Kanban Replenishment	An inventory strategy in which the supplier builds their schedule solely to replenish the consumed inventory of a downstream factory, distribution center, or retailer.
Rate-Based Planning	The establishment of minimum and maximum bounds of capacity flexibility around future demands.
Supplier Broadcast	The sharing of MRP information with integrated suppliers.
Data Exchange	The electronic exchange of demand information between suppliers and manufacturers.
Point-of-Use Material Delivery	The delivery of materials by the supplier to the location (e.g., cell, assembly line, etc.) that the materials will be added.
Quality Certification	A supplier audit process, which over time eliminates the need for inspection of incoming materials.

* DC - distribution center

* MRP - Material Requirements Planning

LESA Scores Prime		LESA Scores FTS		LESA Scores STS	
Overall	56	Overall	23	Overall	54
Supplier Integration	44	Supplier Integration	6	Supplier Integration	56
Lean Production	68	Lean Production	39	Lean Production	49
Distribution Integration	na	Distribution Integration	23	Distribution Integration	56

0 - 40	41 - 74	75 - 100
<i>Beginning the Journey</i>	<i>On the Journey</i>	<i>Approaching World Class</i>

FIGURE 1. LEAN INFUSION SCORES

FTS's weak capabilities are acting as a constraint on the Prime's and STS's emerging supply chain capabilities. This is important knowledge in forming a supply chain improvement strategy.

While Figure 1 provides the companies with a high-level view of its supply chain, more detail data is needed to assist the companies' move toward successfully managing their supply chain. Table 3 decomposes the Lean infusion scores down to the Lean tool and technique level. Thus, each company is able to assess their capabilities in comparison with their partners. This detail is important in aligning rate broadcasts, demand planning, and execution signal information across supply chain partners. For example, the STS has a score of 90 for kanban replenishment under Distribution Integration, while the FTS scored a zero for kanban replenishment under Supplier Integration. This suggests the STS is well equipped to institute kanban replenishment with its suppliers; however, the FTS is not able, at this time, to accommodate the STS. This information provides clearly targeted supply chain improvement opportunities for the supply chain partners.

TABLE 3.
LEAN INFUSION SCORES FOR SUPPLIER
AND DISTRIBUTION INTEGRATION

	Prime	FTS		STS	
Integration Element	SI	DI	SI	DI	SI
Production Development Integration	17	95	15	0	0
Blanket Orders	0	0	9	20	78
Kanban Replenishment	100	0	0	90	58
Rate-Based Planning	0	20	0	0	75
Supplier Broadcast	50	0	16	78	75
Demand Data Exchange	100	100	0	80	100
Point-of-Use Material Delivery	100	10	10	100	15
Quality Certification	85	0	2	100	80
SI = Supplier Integration DI = Distribution Integration					

CREATE MUTUALLY AGREEABLE ACTION ITEMS FOR IMPROVING THE SUPPLY CHAIN

To facilitate the discussion between companies, two maps were developed from the information gathered via site visits and the LESA. The first map is the Supply Chain Metrics Map (see Figure 2). One of the objectives of the Supply Chain Metrics Map is to create awareness about overall supply chain performance. As can be seen, the supply chain has a number of challenges. The value added ratio (value added time divided by total lead time) is only 10.0 percent. Out of 112 days of throughput time, only 90 hours were identified as value added.

The most severe issues appear to be associated with the FTS. The FTS has five value added hours in their portion of the process, but consumes 60 days of lead-time. Part of the FTS's problem is the lead-time for raw materials. This is evidenced by nearly 180 days of raw material inventory at the FTS. However, it would be a mistake to assume that the solution to the supply chain's performance problems is found where the problem is residing. In reality, this is rarely the case. Rather, the solutions to problems reside within systems that may have their causes far removed from the

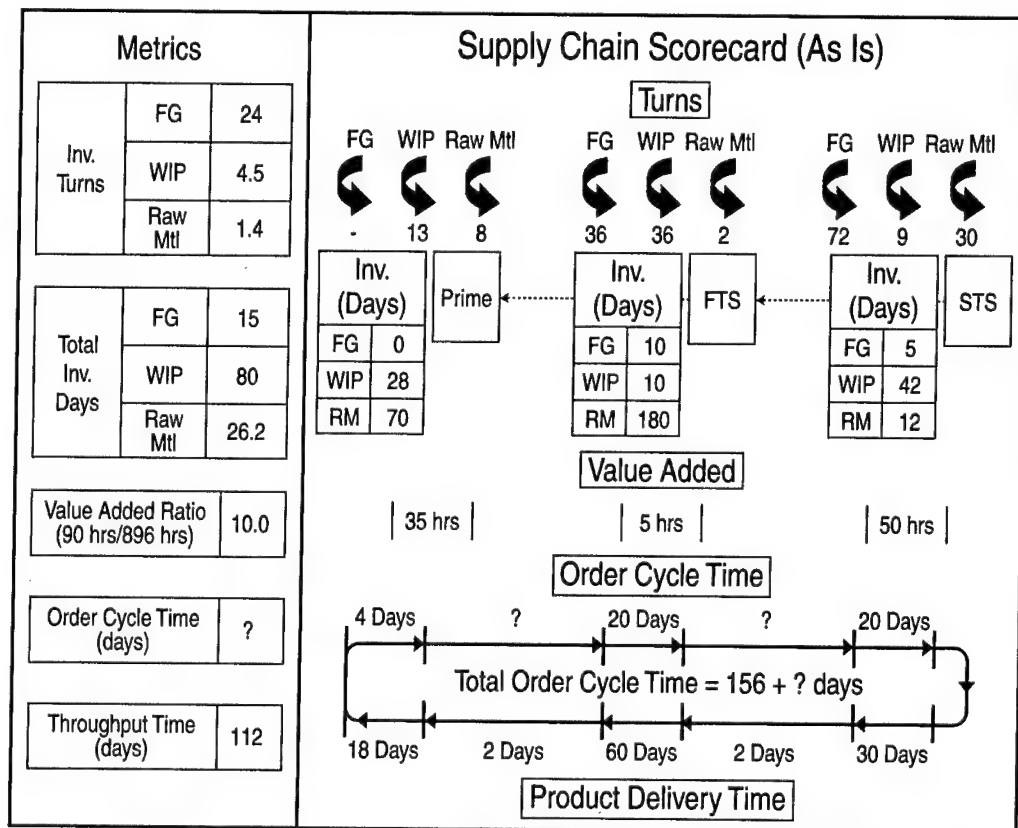


FIGURE 2. SUPPLY CHAIN METRICS MAP

place the problem is identified. Thus, we do not assume the metrics necessarily identify the location of the solution, only the location of the problem.

A second map, the Supply Chain Execution Map, helps identify the possible improvement sources. Figure 3 displays the Supply Chain Execution Map. This map visually details the flow of materials and information within each company and across the supply chain. This map is created prior to the workshop by the facilitators based upon the site visits, LESA results, and metrics (Figure 2). The map shows high-level information and execution flows across the supply chain, while highlighting areas for improvement and coordination. Specific supply chain details, such as demand planning frequency, pull vs. push, batch vs. flow, and upstream/downstream integration methods are displayed.

For example, the map in Figure 3 shows that the supply chain is driven by a classical Material Requirements Planning (MRP) system, with monthly planning *buckets*. Such an infrequent planning frequency causes weak visibility within the supply chain and "blind" execution. It would be like driving a car with your eyes closed and blinking them open every minute. Too much can change in a minute's time. In addition, the MRP system is run sequentially upstream. Such sequential MRP planning approaches

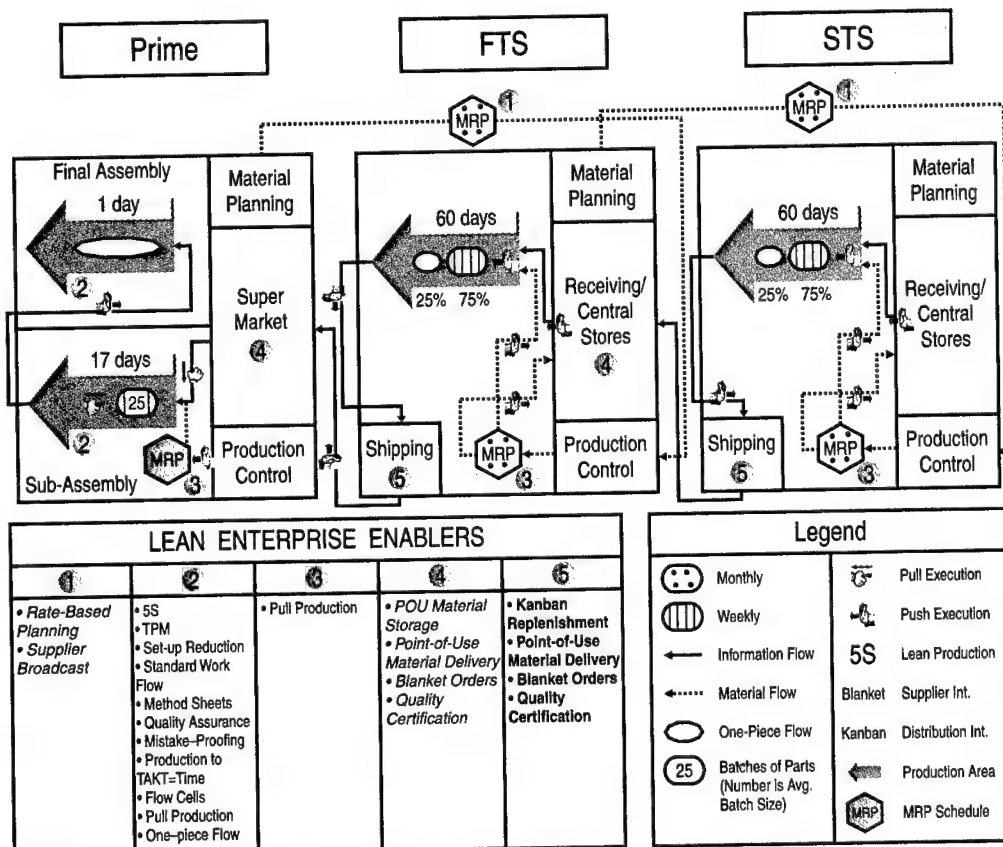


FIGURE 3. SUPPLY CHAIN EXECUTION MAP

combined with long lead-time responses give rise to the order inflation problem identified in the beer game simulation. That is, the Prime will input a demand plan into the MRP. The Material Requirements Planning will translate the demand into upstream purchase orders, adjusting for lead-time and safety stock requirements. The FTS inputs the purchase orders (distorted demand) into their MRP system, which in turn translates these into upstream purchase orders to the STS, adjusting for lead-time and safety stock. The purchase orders received by the STS systematically distort the actual demand known by the Prime. The map begins to hint at simultaneous demand broadcast by the Prime as the solution to remove this source of signal distortion.

With maps in-hand, breakout groups with members across the supply chain form to develop action items necessary to coordinate, communicate, and execute across the supply chain, in addition to continuing the Lean implementation efforts internally. There are two objectives for the breakout session. First, developing a list of action items for each site to complete to assist the site with implementing Lean (i.e., internal action items). Second, developing a list of action items the supply chain must complete to facilitate communication, coordination, and execution across the supply chain (i.e., supply chain action items). Table 4 displays the action items created by the participants in the SCIW.

While the actual action items listed are not groundbreaking and are indicative of the early stage of coordination, they are unique in that all three tiers worked together and agreed on those items with the stated goal of improving the supply chain. More than one of the participants in the SCIW commented that the workshop was, "A unique experience because they often do not get to work within the supply chain." Others mentioned that the unit-of-analysis (the supply chain of one program) makes it easier to talk with their customer.

TABLE 4. ACTION HEMS

Internal Action Items		
STS	FTS	Prime
Process flow chart	Streamline PO process	Check delivery rates
Review product quality records	Verify the degree of Product development with Prime	How do we reduce lead-time?
Supply Chain Action Items		
STS	FTS	Prime
Site visits with FTS and Prime	Process map/flow with STS and Prime	Reusable containers as Kanban signal?
Possibility of managing sub-tier suppliers?	Certify STS	Identify communication issues

ASSIGN RESPONSIBILITY AND EXECUTE ON THE ACTION ITEMS

Creating action items and planning tasks to accomplish those action items is vital; however, it goes for naught if no one executes on that planning. As a participant commented, "it's only interesting until you get to the execution... actually putting it into place." Another senior manager stated that a lack of execution creates bad publicity and "squashes other initiatives." To increase the probability the agreed-to actions are implemented, someone in each company must be given responsibility to oversee the completion of the action items. Establishing lines of communication between firms are also necessary. Many of the actions items involve close coordination between companies.

***"Creating action items and planning tasks
to accomplish those action items is vital;
however, it goes for naught if no one
executes on that planning."***

FOLLOW-UP

Instituting follow-up procedures is crucial for sustaining the initiatives. Milestones should be established and procedures for monitoring the progress should be developed. In addition, protocols for resolving unforeseen issues need to be established. If individuals are willing to move forward on implementing the action items, they must be able to see the fruits of their labor.

RESULTS FROM SCIW

After the workshop, the FTS and STS worked together to map their value-stream capabilities. Based on that work, several processes were altered to increase the efficiencies between the companies. According to one of the action items, the STS toured the FTS's facilities. Prior to this time the STS did not know how their part was used by the FTS. The tour also provided an opportunity for the STS to begin showing the FTS how a Lean enterprise would work to their mutual benefit.

The Prime-FTS-STS detailed supply chain mapping exercise, which was one of the action items, was completed several months after the workshop. This mapping exercise yielded some insights. In one case, the STS produced a welded assembly for the FTS. The existing supply chain had the FTS order, receive, and inspect the components on behalf of the STS, then send the inspected components down to the STS for assembly. The supply chain was changed so that the STS was certified to order, receive, and

inspect these parts directly, without going through the FTS verification stage. This eliminated weeks from the overall lead-time.

Regarding another example, an FTS manager related:

When they weld the two [housing] halves together there's an X-ray that gets done on that girthwell, and we always brought them in here and had the X-ray done at [our facility], and then...you know, you shipped the parts back again so you got this going from [their facility] to [our facility] to [them] to [us] and back and...we decided that was crazy to do that, so [they] found a supplier down there, an X-ray house, that could do that girthwell X-ray.

Beyond product interaction issues, the action items from the workshop lead to higher levels of trust and responsibility between the FTS and STS. For example, the FTS began working with the STS using a blanket purchase order, thus handing replenishment responsibility to the STS. In addition, the STS was able to elevate their product responsibility. This change reduced the friction from integrating the final assembly by shifting this total responsibility to one location.

***"Beyond product interaction issues,
the action items from the workshop lead
to higher levels of trust and responsibility
between the FTS and STS."***

There were adjustments that had to occur between both sites to allow the STS to supply the entire component. The FTS Director of Materials recalled one of those adjustments on the FTS part,

...[the STS] put their hands up for a while because they felt some of the cleaning [requirements], for instance, was a little too tough for them, they weren't quite ready for that. So that was one of the areas where we either did lose some requirement or we could have loosened the requirements and they eventually came around and said, okay, I think we can do that. But there were a number of technical interchanges between our guys and theirs to see...where we actually worked through, you know, what can we do, what can't we do.

The Prime and FTS also participated in some post-workshop activities, including more detailed value stream mapping and facility tours. One of the benefits of this interaction was introduction of some joint Lean/Six Sigma training across both facilities. All of these efforts were viewed as highly beneficial to the two companies, as the elusive *win-win* began to be realized. The managers realized that none of these improvements could have been realized without a direct dialogue for motivating and identifying these opportunities.

CONCLUSION

Coordinating the supply chain across organizational boundaries may be one of the most difficult aspects of supply chain management. Many firms simply are unaware of the fundamental dynamics of supply chains, but even those firms that are enlightened enough to understand these dynamics are often unable to realize inter-organizational coordination. Often the most effective supply chains have a dominating organization that sees the benefits of supply chain coordination and forces the rest of the supply chain to comply (i.e., Wal-Mart). Many supply chains, however, either do not have a dominant organization, or the dominating organization is unenlightened. In these instances, coordinating the supply chain is most difficult.

The methodology described in this paper is an effective means to develop inter-organizational coordination. To achieve supply chain coordination, companies must first be made aware of the fundamental dynamics of supply chains. Awareness can disengage the individual personalities within different organizations, and allow members of the supply chain to objectively view their value stream. Then, the individual organizations can define and measure the current state of their supply chain and finally agree to corrective actions that benefit the entire supply chain.



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ENDNOTES

1. The full version of the LESA is comprised of three operational modules (supplier integration, Lean production, and distribution integration), two organizational dynamics modules (management level, and front-line level), and one performance measurement module.

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